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I am enclosing herewith a dissertation written by Janet Therese Knoedler entitled "Backward Linkages to Industrial Research in Steel, 1870-1930." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

Anne Mayhew

Professor Anne Mayhew, Major Professor

We have read this dissertation
and recommend its acceptance:

Walter C. Neale

Sidney L. Carroll

Karmen N.T. Crowther

Accepted for the Council:

C W Minkel

Associate Vice Chancellor
and Dean of the Graduate School

BACKWARD LINKAGES TO INDUSTRIAL RESEARCH IN STEEL, 1870-1930

A Dissertation

Presented for the

Doctor of Philosophy

Degree

Tne University of Tennessee, Knoxville

Janet Therese Knoedler

December, 1991

DEDICATION

This dissertation is dedicated to my parents,

Mr. Joseph Bernard Knoedler

and

the late Mrs. Rose Louise Geier Knoedler,

and my siblings,

Karen Louise Knoedler,

Thomas Bernard Knoedler,

Michael Gerard Knoedler,

and the late Gary Joseph Knoedler.

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ABSTRACT

Following Nathan Rosenberg's lead, this dissertation emphasizes the incremental, cumulative innovations that followed on the heels of major innovations in steel products and processes, innovations which, though economically important, have been neglected. Crucial inducements for these incremental improvements to steel were the early industrial testing activities by steel consuming firms, and the subsequent interaction and cooperation between steel consuming and steel producing firms. This study concludes that a substantial amount of backward-linked industrial research into steel developed during the late nineteenth and early twentieth centuries through efforts of prominent steel consuming firms and technical associations to improve steel products and processes. The type of industrial research that developed in the manufacture and processing of steel was part of an important transition in American industry from the use of rule-of-thumb methods to the use of scientific methods. This backward-linked industrial research brought together firms and technical associations interested in improving the quality of steel materials, and, in so doing, helped to promote the development of broadly-based cooperative industrial research efforts in the 1910s and 1920s.

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CHAPTER 1

INTRODUCTION AND OVERVIEW OF THEORETICAL AND HISTORICAL ISSUES

Section 1. Introduction

This dissertation will describe backward linkages to industrial research in the manufacture and processing of steel between 1870 and 1930. The intent is a contribution to the ongoing efforts of economists to look inside the "black box"[1] of technological change.

Industrial research in the manufacture and processing of steel occurred in a different fashion than described in much of the literature on American corporate R&D. Following Nathan Rosenberg, I emphasize the incremental, cumulative innovations that followed on the heels of major innovations in steel products and processes, incremental innovations that, though economically important, have been neglected. Crucial inducements for these incremental innovations were the early industrial testing activities of steel consuming firms and the subsequent interaction and cooperation between steel consuming and steel producing firms.

The broad findings of this study are:

1) A substantial amount of backward-linked industrial research into steel developed during the late nineteenth and early twentieth centuries through efforts of prominent steel consuming firms and

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[1]Nathan Rosenberg, Inside the Black Box (New York: Cambridge University Press, 1982), p. vii.

technical associations directed at improving steel products and processes. These research efforts have been overlooked because they did not involve development of new products and processes but, rather, refinement and improvement of existing products and processes.

2) The type of industrial research that developed in steel was part of an important transition in American industry from rule-of-thumb to science.

3) This backward-linked industrial research brought together firms and technical associations interested in improving the quality of steel materials, and, in so doing, helped to promote broad-based cooperative research efforts in the 1910s and 1920s. These past cooperative industrial research efforts may bear on the current debates about the efficacy of cooperative industrial research.

Industrial research and technological change have been insufficiently explored by economists. Economic studies have emphasized static efficiency rather than dynamic growth, and therefore assume fixed production techniques and given levels of technological information. When technological change has been examined, the process of change is usually tucked away inside the "black box" while economists instead focus on the impact of technological change on aggregate economic growth and progress. However, some attention has been given to the incentives for, and the impact of, technological change at the level of the firm. From these latter studies comes the typical microeconomic view of the relationship between industrial structure and industrial research: firms conduct industrial research to gain a competitive advantage over rival firms through developing new products or reducing manufacturing costs for existing products. Little attention has been paid to research designed to improve the quality of existing products. This standard view has been reinforced by standard assumptions about the performance of firms and by the visibility and importance of new products in the real world.

Most of the previous literature on industrial research deals with the post-World War II era for which data is abundant. Due to a paucity of systematic longitudinal data on the industrial research activities of firms prior to this period, it has been difficult to evaluate the general causes and consequences of the industrial research undertaken in the early twentieth century.[2] Much of the work done on early industrial research is necessarily restricted to case studies of particular technologies, industries, or firms. Noteworthy studies include descriptions of industrial research pioneers such as General Electric, du Pont, AT&T, and Eastman Kodak which established in-house industrial research laboratories at an early date to protect their market positions in technologically advanced and advancing industries. Such early moves into industrial research helped such large firms gain, and maintain, competitive advantages over their competitors long before World War II.[3]

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[2]It should be noted that there are considerable conceptual problems with statistical analyses of industrial research; the relevant questions concerning quantitative measures of industrial research inputs and outputs are summarized by F. M. Scherer and David Ross in Chapter 17 of Industrial Market Structure and Economic Performance (Boston: Houghton-Mifflin Co., 1990).

[3]See, for example, David A. Hounshell and John K. Smith, Science and Corporate Strategy, Du Pont R&D, 1902-1980 (Cambridge: Cambridge University Press, 1988); Reese Jenkins, Image and Enterprise: Technology and the American Photographic Industry, 1839-1925 (Baltimore: The Johns Hopkins University Press, 1975); and Leonard Reich, The Making of American Industrial Research (Cambridge:

These historical studies have strengthened the prevailing view of industrial research as a form of non-price competition through new product development.

Yet significant industrial research activity of a different sort existed before World War II, and in many important cases, much earlier, during the "statistical 'dark ages'"[4] of industrial research. In-house industrial research laboratories were established by many firms, large and small, between 1870 and 1930. More to the point here, a substantial amount of this early industrial research was directed toward different goals than development of revolutionary new products and processes. This alternative mode of industrial research was aimed both at developing a body of consistent scientific knowledge about existing products and processes and at finding systematic ways of obtaining that knowledge. It was important in inducing a fundamental transition in many industries from older "rule-of-thumb" industrial procedures to newer and ultimately more reliable science-based industrial methods.

An excellent example of this alternative mode of industrial research is found in the manufacture and processing of steel between 1870 and 1930. To find the record of this research the activities of both steel producing firms and steel consuming firms must be examined. Relatively little research was conducted in the steel industry itself: large steel producing firms in the United States were slower to recognize the value of industrial research than were large firms in

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Cambridge University Press, 1985).

[4]David Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing," 1899-1945 (Ph.D. dissertation, Stanford University, 1981), p. 2.

other major industries. With the formation of U.S. Steel in 1901, the steel industry became a stable dominant firm oligopoly; and, as a result, there was little pecuniary incentive on the part of large steel firms to compete by using industrial research to create new products or processes, or to improve knowledge of standard products and processes.

By contrast, a substantial amount of research into steel was conducted by steel-consuming firms and technical associations, creating crucial backward linkages to industrial research and spawning considerable technological change in steel products and processes in the first part of this century. Prominent steel consuming firms initially performed industrial research to improve the quality of the steel used by their enterprises. Such efforts by steel consuming firms eventually induced more industrial research on the part of steel producing firms, although not in any significant degree until the 1920s. This broader institutional context for industrial research would be neglected in firm- or industry-level analysis.

This dissertation is a study of the causes, consequences and implications of these backward linkages to industrial research in steel, and will proceed as follows. The remainder of Chapter 1 will treat theoretical and historical issues concerning the economics of technological change and industrial research as they relate to the history to be recounted in this dissertation. Chapter 2 will describe the relevant technological and business conditions in the U.S. steel industry before 1900. Chapter 3 will discuss the development of backward-linked industrial research into steel by one prominent steel consuming firm, the Pennsylvania Railroad (PRR), utilizing primary source materials from the records of the Pennsylvania Railroad Test Department in the Pennsylvania Railroad archives held at Hagley Museum and Library. Chapter 4 will discuss the American Society for Testing Materials, a technical association that utilized a novel institutional framework to bring together steel producers and consumers to achieve consensus about improvements in steel, using materials from the published Proceedings of the society and contemporaneous issues of Iron Age, the steel industry's primary trade journal. Chapter 5 discusses the effects of the research efforts of steel consuming firms and technical associations on industrial research into new steel products and processes, relying on materials from contemporaneous issues of Iron Age. The concluding chapter will consider the implications of this backward-linked industrial research for the study of technological change in both historical and present-day contexts.

Section 2. Toward an Alternative Understanding of Industrial Research

The standard understanding of industrial research assumes it to be conducted by a single firm and directed toward development of new products and processes. By this standard, there was practically no industrial research in the American steel industry between 1870 and 1930. A more appropriate model for the alternative mode of industrial research taking place in the manufacture and processing of steel must incorporate two elements: a broader institutional context for innovation and incremental cumulative improvements in existing products and processes occurring over a long period--a process that was both knowledge- and technique-deepening. This alternative understanding of industrial research will require use of an unfamiliar concept--multidirectional innovation. Some familiar concepts--such as incentives for industrial research and the relationship between market structure and industrial research will also be used.

a. A Multidirectional Process of Innovation

The dominant models of industrial research treat the process as involving three separate, albeit related, activities--basic research, applied research, and development, with movement implied from basic research through applied research to development, in unidirectional fashion. Basic research refers to the pursuit of new knowledge, for its own sake, or, more likely, in order to establish the scientific principles underlying some commercially exploitable future product or process. Applied research refers to short-term research projects with fairly predictable results, carried out for specific commercial aims. Development refers to the fairly routine matter of taking these applied research results and putting them into large-scale commercial production.[5]

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[5]See, for example, Edward Ames, "Research, Invention, Development and Innovation," American Economic Review 1961, p. 373; Edwin Mansfield, The Economics of Technological Change (New York: W. W. Norton & Co., Inc., 1968), p. 47; Mansfield et al, The Production and Application of New Industrial Technology (New York: W. W. Norton & Co., Inc., 1977), p. 2; Mansfield et al, Research and Innovation in the Modern Corporation (New York: W. W. Norton & Co., Inc., 1971), pp. 112-15; and National Association of Manufacturers Patents and Research Committee, Trends in Industrial Research and Patent Practices (National Association of Manufacturers, 1948), p. 5.

This unidirectional model of industrial research is not applicable to many U.S. industries between 1870 and 1930. The first applications of science to industry did not proceed from basic science to industrial applications but, instead, moved in the opposite direction. Much of the pure scientific research conducted in academic settings was actually induced by the most financially promising technologies.[6] A model of industrial research applicable to the steel industry, and possibly to other American industries during this period, should allow for information flows from industry to science and back to industry, in a multidirectional process of innovation. The multidirectional process incorporates three elements that may contradict the more typical economic view of technological change: incremental innovation, diffusion, and users' innovative efforts.

First, a multidirectional model of innovation should describe ongoing innovation that builds on the established technology of existing products and processes, and should emphasize the incremental, cumulative improvements that are the heart of such a process. Incremental innovations are less visible than revolutionary innovations. Admittedly, it is difficult to identify individual incremental innovations

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[6]David Mowery and Nathan Rosenberg have described how industrial research agendas in the late nineteenth century were initiated in industrial settings and were then moved to academic settings. See Technology and the Pursuit of Economic Growth (Cambridge: Cambridge University Press, 1989), p. 9. See also Stephen J. Kline and Nathan Rosenberg, "An Overview of Innovation," in The Positive Sum Strategy, eds., Ralph Landau and Nathan Rosenberg (Washington, D. C.: National Academy Press, 1986), pp. 284-94; and John Rae, "The Application of Science to Industry," in Alexandra Oleson and John Voss, eds., The Organization of Knowledge in Modern America, 1860-1920 (Baltimore: The Johns Hopkins University Press, 1979), p. 249.

amidst an "interrelated clustering of innovations."[7] Yet they are the most common form of innovative activity in many industries.[8] Moreover, there is a more certain, and perhaps higher, economic pay-off for firms that direct their innovative efforts toward incremental innovation; for this reason, firms may focus their research efforts on modest design improvement or projects with a short payoff time.[9]

Second, a multidirectional model of innovation requires explicit consideration of the way in which new techniques and new products are diffused throughout an industry. In typical models the industrial research process is assumed to culminate in an already perfected innovation which is then made available for widespread commercial use

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[7]Rosenberg, Inside the Black Box, p. 59.

[8]The typical conceptualization of technological change as a radical shift in the production function is problematic because it focuses on "breakthroughs in scientific knowledge [that] bring with them whole new ranges of more efficient factor combinations for producing a commodity," but ignores the "numerous sources of pressure against production possibility frontiers which cause them to be extended or shifted in limited regions." See Rosenberg, Perspectives in Technology (Armonk, New York: M. E. Sharpe, 1985), pp. 66, 77-78; and also Giovanni Dosi, "Technological paradigms and technological trajectories," Research Policy 1982, pp. 158-59.

[9]Statistics indicate that firms devote more industrial research resources to making improvements in existing products, while only a small amount of these resources are directed toward basic research. See Richard R. Nelson et al, Technology, Economic Growth, and Public Policy (Washington, D. C.: The Brookings Institution, 1967), p. 85. Economic motives such as product differentiation, protection of market share, and "quick and certain returns" motivate firms to be conservative in their industrial research efforts. See D. Hamberg, "Invention in the Industrial Research Laboratory," The Journal of Political Economy, April 1963, pp. 100-03. However, many firms have acknowledged that development of new products was more important to their long-term viability. See National Association of Manufacturers Patents and Research Committee, Trends in Industrial Research and Patent Practices, p. 6; and Rosenberg, Perspectives in Technology, p. 125.

or diffusion--the problem is simply how to market the innovation and increase the rate of diffusion.[10] In a multidirectional process, diffusion includes a long continuous stream of incremental improvements on the initial innovation during which users begin to adopt the new product or process while many technological 'bugs' are worked out and important improvements are made. This is a process of "learning by doing" where "use promotes improvement."[11] Moreover, the incremental innovations produced through this process may have greater economic importance

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[10]Many economists have, therefore, simply focused on the rate of diffusion, observing that it is typically a slow process, although the rate of diffusion may increase if innovations become more profitable: for example, Edwin Mansfield notes that diffusion proceeds rapidly or slowly, "subject, of course to the constraints imposed by the marketplace" (The Economics of Technological Change, p. 112). Economic determinants of the rate of diffusion include the innovation's economic advantage over older methods or products; the level of financial and other resources needed to introduce a given innovation by a given firm; the uncertainty associated with the innovation; increased market demand for a related new product or process; availability of new specialized materials and equipment; improved labor skills; credit availability; and reports on a given innovation in the relevant technical literature. See Mansfield, The Economics of Technological Change, p. 119; Mansfield, Industrial Research and Technological Innovation (New York: W. W. Norton & Co., Inc., 1968), p. 153; and Nelson et al, Technology, Economic Growth, and Public Policy, p. 107.

[11]S. C. Gilfillan, The Sociology of Invention (Chicago: Follett Publishing Company, 1935), pp. 5, 8. In Gilfillan's view, even a major technological breakthrough was actually a "perpetual accretion of little details, probably having neither beginning, completion nor definable limits." Rosenberg also describes diffusion as a "period when critical inventive activity and essential design improvements and modifications are still going on;" see Perspectives in Technology, pp. 192-93; see also Mansfield et al, The Production and Application of New Industrial Technology, p. 17; and Rosenberg, Inside the Black Box, p. 110. The idea of learning by using differs somewhat from the traditional learning curve in that the traditional learning curve implies increasing efficiencies from continuing to use the same production function, while learning by using implies small but significant outward shifts in the production function.

than major technological breakthroughs due to the fact that they enable full industrial exploitation of major innovations.[12]

Third, explicit consideration of incremental innovation and diffusion call for examination of a broader institutional context that incorporates both the activities of producing firms' industrial research labs and the innovative activities of consuming firms.[13] In fact, many innovations originate from industrial consumers' needs rather than frontier scientific research, establishing important linkages between producing and consuming firms, and allowing potential 'consumers' of the innovated process or product to respond to each incremental innovation with suggestions for further innovations.[14]

A multidirectional process is one in which there is

> . . . sustained two-way flow of information . . . . an ongoing search activity that is shaped and structured not only by economic forces that reflect cost considerations and resource endowments but also by the present state of technological knowledge, and by consumer demand for different categories of products and services.[15]

A multidirectional process of innovation places the focus on the learning aspects of innovation and the interdependence between producing and

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[12]Kline and Rosenberg, "An Overview of Innovation," pp. 282-83; and Rosenberg, Inside the Black Box, pp. 4, 56, 62.

[13]Such a process is outlined in Giovanni Dosi, "The nature of the innovative process," in Dosi et al, eds., Technical Change and Economic Theory (London: Pinter Publishers, 1988), p. 223.

[14]William J. Abernathy and Kim B. Clark, "Innovation: Mapping the Winds of Creative Destruction," Research Policy 1985, pp. 7-13.

[15]Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 8.

consuming firms, rather than the efforts of a particular production unit.[16] A cautionary note from Rosenberg needs to be added, however; it is more difficult to evaluate the economic consequences of industrial research efforts in the context of such a multidirectional model. When consuming firms actively participate in shaping the direction of producing firms' innovations so that they are relevant to their own needs, the pecuniary benefits may flow into consuming rather than into producing industries, yielding no directly observable benefits for innovating firms.[17]

b. Market Incentives, Market Structure, and Industrial Research

In standard models of industrial research, the primary incentive for industrial research at the firm level is the profit motive--the firm's expectations of enhanced profits accruing from new or improved products or processes. At the industry level it is the market structure within which innovation occurs that determines the extent of industrial research: some degree of imperfection is required so that innovating firms can reap the expected above-normal profits and some degree of

[16]Such models are beginning to be formally developed: see, for example, Bengt-Ake Lundvall, "Innovation as an interactive process: from user-producer interaction to the national system of innovation," in Dosi et al, eds., Technical Change and Economic Theory (London: Pinter Publishers, 1988), pp. 349-50.

[17]Rosenberg, Perspectives in Technology, p. 70.

competition is required so that industry participants are compelled by oligopolistic rivalry to engage in innovative activity.[11]

At the firm level, the typical economic incentives for innovation do not adequately describe the reasons for innovation in the U. S. steel industry between 1870 and 1930. Given that steel consuming firms and technical associations were working to improve steel products and processes, one might predict that the profit motive or various demand-side factors would have spurred steel producing firms to do the same to avoid losing their customers; yet steel producing firms lagged behind in their industrial research efforts.

Some less typical firm-level incentives may be more useful in explaining the motives for research on the part of steel consuming firms. First, "technological disequilibria" prompt many incremental innovations, of the sort that occurred in steel, because advances in one technology cause technical imbalances in complementary technologies and

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[11] See, for example, Arrow, "Economic Welfare and the Allocation of Resources for Invention," in Rosenberg, The Economics of Technological Change (Middlesex, England: Penguin Books, 1971), 175; Partha Dasgupta and Joseph Stiglitz, "Uncertainty, industrial structure, and the speed of R&D," Bell Journal of Economics, Spring 1980, p. 27; Dosi, "Technological paradigms and technological trajectories," p. 147; Kamien and Schwartz, "Market Structure and Innovation: A Survey," Journal of Economic Literature 13, # 1 (1975), pp. 8, 15; Mansfield, The Economics of Technological Change, pp. 17, 35, 105; Mansfield et al, The Production and Application of New Industrial Technology, p. 10; Richard R. Nelson, "The Economics of Invention: A Survey of the Literature," The Journal of Business, April 1959, p. 101; Nelson, Technology, Economic Growth, and Public Policy, pp. 29-30, 35-42; Rosenberg, Inside the Black Box, p. 228; and Jacob Schmookler, "Economic Sources of Inventive Activity," in Rosenberg, ed., The Economics of Technological Change, p. 135. Rosenberg makes the important point that, given what are at best uncertain expectations about profits, firms may engage in 'satisficing' behavior, exploring "alternative technologies . . . only when a firm's profit level falls below some minimum acceptable level;" see Perspectives in Technology, p. 125.

induce technical experts to modify these complementary technologies in order to bring the technological system back into balance.[9] Second, there may be a wide range of potential competing technologies available: in such cases market mechanisms may exhibit a "general weakness . . . in the ex ante selection of technological directions especially at the initial stage of the history of an industry;"[10] however, consuming firms may have a strong incentive to explore various technologies. Consuming firms may produce and disseminate technological knowledge with the intention of promoting particular technological directions by producing firms.

At the industry level, the relationship between industrial research and market structure may yield some insight into the slowness of the steel industry to move into industrial research.[11] In general, it is assumed that large oligopolistic firms will be better situated financially and more motivated to engage in industrial research; thus market power

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[9]Rosenberg, Perspectives in Technology, p. 117; and Inside the Black Box, p. 61. David Landes made a similar point in considering technological change and industrial development in Western Europe from the Industrial Revolution through the first half of the twentieth century in The Unbound Prometheus (Cambridge: Cambridge University Press, 1985).

[10]Dosi, "Technological paradigms and technological trajectories," p. 159.

[11]It should be noted that the relationship between industry structure and industrial research has been one of the major debates in the literature since 1942 when Joseph Schumpeter stated that "[the large-scale establishment] has come to be the most powerful engine of . . . progress." See Capitalism, Socialism, and Democracy, 3d. ed., (New York: Harper & Row, 1950), pp. 82-83.

should produce greater innovative activity.[12] But industrial research can also provide the means for a smaller firm to increase market power.[13] Though many empirical studies, relying on post-World War II data, have been conducted to test these theoretical relationships, they have been inconclusive.[14]

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[12]There are a variety of reasons posited. Large firms have the necessary resources for R&D; large firms can diversify their R&D portfolios and thereby reduce the risk for any one project; large firms are better able to wait the long time needed for the pay-off from industrial research; and the large market shares of such firms guarantee that a sizable portion of the economic benefits from research will accrue to it. Also relevant is the idea of economies of scale in R&D --large firms are able to use R&D more effectively to exploit the results in their markets; and there may be economies of scale for the research unit itself. See, for example, Franklin M. Fisher and Peter Temin, "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?," Journal of Political Economy, 1981, pp. 57-58; Kamien and Schwartz, "Market Structure and Innovation: A Survey," p. 8; and Mansfield, The Economics of Technological Change, p. 94. Anne Mayhew observes that this so-called 'Schumpeterian thesis' ". . . was not part of Joseph A. Schumpeter's view of the capitalist process." See "Schumpeterian Capitalism versus the 'Schumpeterian Thesis,'" Journal of Economic Issues, June, 1980, p. 583.

[13]Mansfield outlined the basic argument as follows: "Technological change is a key element in the competitive struggle among firms. The extent and quality of a firm's research and development program can make it an industry leader or head it for bankruptcy." Kamien and Schwartz note several strands to this argument: industrial research can help a firm establish technological barriers to entry; industrial research is one aspect of a firm's rivalrous behavior; past R&D success may lead to greater R&D current R&D effort which in turn may widen the gap between a technological leader and its rivals. Nelson and Winter note the reverse causality--"to the extent that growth is keyed to profitability, successful innovators grow relative to other firms." See Mansfield, The Economics of Technological Change, p. 7; Kamien and Schwartz, "Market Structure and Innovation: A Survey," pp. 12-13; and Richard R. Nelson and Sidney G. Winter, "Forces generating and limiting concentration under Schumpeterian competition," Bell Journal of Economics, Autumn, 1978, p. 525.

[14]See, for example, Mansfield et al, The Production and Application of New Industrial Technology, p. 16; Nelson et al, Technology, Economic Growth, and Public Policy, pp. 48, 66-67, and 71; and Frederic M. Scherer, Innovation and Growth (Cambridge, Massachusetts: The MIT Press, 1989), p. 183. Two studies are worth noting: Hamberg, citing

Only one study has examined the statistical relationship between market structure and innovation in the early twentieth century U.S.: David Mowery concludes that, in general, there is evidence that large firms used industrial research to maintain their advantage over rival firms; there is less evidence that smaller firms gained market share at the expense of larger firms.[15] Other evidence on the pre-World War II era suggests that large firms had higher levels of industrial research activity, based on the dramatic increase in the number of large industrial research laboratories between 1921 and 1930 and the increased concentration of industrial research workers in a few large firms between 1920 and 1940.[16] But many large corporations at the turn of the century were not particularly aggressive in moving into industrial research:

> . . . the largest corporations were preoccupied with the need to consolidate their firms and stabilize their companies'

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several examples, contends that large industrial research laboratories "are likely to confine their research activities largely to extensions and refinements of the profitable products, that is, to improvements within the existing framework, in the interests of consolidation of past gains;" see "Invention in the Industrial Research Laboratory," p. 105. Jesse Markham argued that large firms spend more on industrial research, up to some threshold level, and added that the decision for a firm to invest in R&D required an industry structure where the firms were "large enough to affect the fate of their rivals;" see "Economic Analysis and the Research and Development Decision," in Richard A. Tybout, Economics of Research and Development (Ohio State University Press, 1965), p. 69.

[15] Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing, 1899-1945," pp. 2-4.

[16] Howard R. Bartlett, "The Development of Industrial Research in the United States," in Research--A National Resource, vol. II (Washington, D. C., National Research Council, 1940), pp. 37-38; and George Perazich and Philip M. Field, Industrial Research and Changing Technology (Philadelphia: Work Projects Administration, National Research Project, Report No. M-4, 1940), p. 10.

positions in their respective markets. . . . The rewards for a successful performance were great and the risks far less than they were for ventures along new technological paths.[17]

And many small firms also established significant research labs with active industrial research programs by 1940; especially noteworthy were the "technical uniqueness"[18] of some small firms and the assistance rendered to small firms by professional societies and technical literature.

Thus there are important differences in the rates at which, and the extent to which, various industries and firms moved into industrial research. Firms in technologically advanced industries used industrial research to achieve market stability or to protect their market share. Two of the most successful industrial research pioneers--General Electric and AT&T used research to gain control of their markets, and protected these markets by "maintaining corporate product areas through broad-ranging patent-gathering activity as well as achieving particular scientific or technical goals;"[19] research was used, therefore, not so

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[17]Louis Galambos, "The American Economy and the Reorganization of the Sources of Knowledge," in Alexandra Oleson and John Voss, eds., The Organization of Knowledge in Modern America, 1860-1920 (Baltimore: The Johns Hopkins University Press, 1979), pp. 274-75. Rosenberg also notes that the major steel producing firms were slow to move into industrial research. See Technology and American Economic Growth (New York: Harper & Row, Publishers, 1972), p. 153.

[18]Fairfield E. Raymond, "Research--A Resource to Small Companies," in National Research Council, Research--A National Resource, vol. II (Washington, D. C., National Research Council, 1940), p. 78.

[19]Leonard S. Reich, "Research, Patents, and the Struggle to Control Radio: A Study of Big Business and the Uses of Industrial Research," Business History Review, Summer 1977, p. 210. See also Kendall Birr, "Industrial Research Laboratories," in Nathan Reingold, ed., The Sciences in the American Context (Washington, D. C.: Smithsonian Institution Press, 1979), p. 197; and Reich, "Industrial Research and the Pursuit of Corporate Security: The Early Years of Bell Labs," Business History Review, Winter 1980, p. 506.

much to take advantage of the special characteristics of their science-based industries but to protect market shares. Charles Reese, an early manager of du Pont's industrial research lab, emphasized the same kind of non-price competition:

> . . . one of the greatest benefits from maintaining a research organization in any industry, and particularly in the chemical industry, is the fact that it will enable the manufacturer to keep ahead of the art, and thus be in a strong position to meet competition, both in quality and the cost of the product.[30]

Yet Frank Jewett, chief engineer for AT&T's early industrial research lab, emphasized an important point: firms with the most conservative attitudes toward industrial research were "the oldest and . . . those which existed long before the science of their art had been developed."[31] In the case of steel, the established nature of the existing technology and the stability of the dominant firm oligopoly after 1900 were not conducive to industrial research.

c. Summary

The considerable industrial research into steel products and processes that existed between 1870 and 1930 would be overlooked if the standard definition of industrial research is applied. In order to examine the alternative mode of industrial research in steel, an

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[30]Charles L. Reese, "Industrial Benefits of Research," National Research Council, Reprint and Circular Series of the National Research Council, No. 18, p. 4.

[31]Frank B. Jewett, "Industrial Research," National Research Council, Reprint and Circular Series of the National Research Council, No. 4, p. 15.

alternative understanding of industrial research based on a multidirectional process of innovation must be combined with an understanding of industry-specific incentives and conditions conducive to industrial research.

Before addressing the particular case of innovation in the manufacture and processing of steel, some special characteristics of turn-of-the-century industrial research must be described in some detail--the role of industrial testing and the transition from rule-of-thumb to science. The cooperative nature of much of this research will also be commented upon.

Section 3. Testing as Industrial Research

Much of the industrial research to be described in this dissertation is and was labelled as industrial testing. Systematic testing of commercial materials and products began in the late nineteenth century. Testing enabled, and in many cases promoted, widescale use and improvement of many commercial products; yet testing is an aspect of industrial discovery that is not always accorded the status of industrial research. Testing is often dismissed as routine scientific drudgery or treated as a pre-industrial research stage; or, in typical unidirectional models, testing is subsumed under applied research or development.[31] But, in actual fact, industrial testing played a significant role in the innovation of steel products and processes.

From a theoretical standpoint, testing is important to every aspect of a multidirectional process of innovation. Such a process requires learning by using, and testing is arguably one of the primary means by which scientific and technological facts about existing products are learned. Testing enabled steel consuming and producing firms to learn the precise chemical compositions and physical performance characteristics required for quality steel. Testing is essential to diffusion: through testing, a body of technological information on ways to improve products and processes is compiled and disseminated and a series of incremental innovations are achieved. Moreover, testing has particular relevance for multidirectional processes of innovation that rely on interaction between consuming and producing firms. When new uses are found for existing materials, testing is used by both consuming and producing firms to identify the requirements for these new

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[31]Mowery and Rosenberg characterize those engaged in performing the testing and grading work in early industrial research labs "as not yet performing activities that should be regarded as research. Rather, they were engaged in a variety of routine and elementary tasks such as the grading and selection of materials, assaying, quality control, and writing of specifications . . . . tasks that were elementary from the point of view of their scientific content." See <u>Technology and the Pursuit of Economic Growth</u>, p. 37. As Alfred Chandler argues, in order for the emergence of successful in-house product and process development, it was essential that testing and standardizing functions be separated from product and process development. In his view, manufacturing firms were induced to institute testing laboratories to meet the requirements of users, but they gradually moved beyond these testing activities to apply "science to the development of specific processes and products." See "From Industrial Laboratories to Departments of Research and Development," in Kim B. Clark et al, <u>The Uneasy Alliance</u> (Boston: Harvard Business School Press, 1985), pp. 54, 61.

applications and serves as a basis upon which to communicate their findings to the other parties.[33]

From a historical standpoint, testing holds a place of scientific and economic importance in the emergence of American industrial research because it helped to promote wide-scale diffusion of, and incremental improvements in, many industrial products and processes. As Rosenberg observes, the "first phase of the application of science to industrial processes and products consisted in testing, measuring, analyzing, and quantifying processes and products already in place."[34] Testing made two important contributions to the alternative mode of industrial research that will be described in this dissertation. First, much early research by U.S. firms consisted not so much in developing new products and processes as in scientifically analyzing (or testing) existing products and processes. Industrial testing personnel established, for the first time, new scientific methods for determining the reliability and wider applicability of existing products.[35] Second,

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[33]Abernathy and Utterback, "Patterns of Industrial Innovation," Technology Review June/July 1978, pp. 45-46.

[34]This was true for industrial research laboratories in the steel and concrete industries, as well as for many other early industrial research labs established before 1918. These labs "contributed principally information rather than invention or new scientific insights, but, to cite only one example, with their aid, the life of a rail increased from two years to ten, and the car weight it could bear from eight tons to seventy in the forty years between the end of the Civil War and 1905. Only a very few new technologies have had equal scientific significance." See Rosenberg, How the West Grew Rich (New York: Basic Books, Inc., Publishers, 1986), pp. 246-47.

[35]This "growth of knowledge with respect to the behavior of materials was to lead, in myriad ways, to a prolongation of the useful lives of the products made of these materials." See Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 42.

testing enabled compilation of the first systematically collected body of information on materials, obtained both through routine lab work and through special investigations. Testing thus promoted important industrial innovations rather than scientific advances, enabling industrial scientists of the late nineteenth century to begin to exploit the basic scientific knowledge that had been available for some time.[36]

Some early testing activities have generally been acknowledged as being important. True industrial discovery occurred in at least one of these early testing labs, that of the Pennsylvania Railroad:

> . . . in the seventies and eighties, when business men had little faith in what the chemist could do, and when the chemist had little knowledge of what he could do for the business men, Dudley's work was true industrial research.[37]

The Pennsylvania testing lab was "strictly speaking, . . . not a research laboratory, but it would be difficult to determine exactly where testing and analysis stopped and research began." Many early testing labs, initially relegated to handling testing and analysis for their firms "also contrived to find opportunities for longer-range studies, and they were increasingly encouraged to do so by management."[38] By the turn of the century, industrial testing began to produce important and tangible results and came to be recognized as an important activity for business

[36]As Rosenberg describes the scene, the U.S. was rapidly industrializing, and "encountering all sorts of situations at the level of newly emerging technologies where further improvement and progress required drawing upon the existing fund of scientific knowledge." See "The Commercial Exploitation of Science by American Industry," in Kim B. Clark et al, The Uneasy Alliance (Boston: Harvard Business School Press, 1985), p. 25.

[37]Bartlett, "The Development of Industrial Research in the United States," p. 27.

[38]Rae, "The Application of Science to Industry," pp. 261, 264.

firms; American industry hired professional industrial scientists in increasing numbers.[39]

Testing was a major activity in most firms' industrial research labs over the first four decades of the twentieth century. In 1917 testing and standardization were described as important industrial research activities in many manufacturing firms; this was still true in 1940.[40] Two early practitioners of industrial research included testing within the purview of industrial research functions.[41] But, even though testing activities were prominent among the activities of the early industrial research labs, testing activities were often denigrated: "it is customary nowadays to speak of them scornfully, if at all, in any report on 'research.'"[42] As the relationship between science and industry matured in the later twentieth century,

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[39]W. David Lewis, "Industrial Research and Development," in Melvin Kranzberg and Carroll W. Russell, Jr., eds., Technology in Western Civilization, vol. II (New York: Oxford University Press, 1967), p. 622.

[40]Arthur Percy Morris Fleming, Industrial Research in the United States of America (London: Published for the Department of Scientific and Industrial Research by Her Majesty's Stationery Office, 1917), pp. 2-4; and Perazich and Field, Industrial Research and Changing Technology, p. 4.

[41]Furnas included the following: improvement in product quality, elimination of technical problems, standardization, and improvement of customer and public relations--all aspects or effects of testing, among the typical activities of industrial research labs. See Research in Industry (Princeton, N. J.: D. Van Nostrand Co., Inc., 1948), p. 2. Reese observed that "it is very difficult to separate true research from efficiency control. See "Industrial Benefits of Research," National Research Council, Reprint and Circular Series of the National Research Council, No. 18, pp. 3-4.

[42]Harvey N. Davis and C. E. Davies, "Industrial Research by Mechanical Engineers," in National Research Council, Research--A National Resource, vol. II (Washington, D. C., National Research Council, 1940), p. 330.

> routine testing itself tended to be monotonous and unattractive to highly trained personnel; in time it was increasingly assigned to non-professional employees and even handled by mechanical or electronic devices.[43]

The transition in the view of testing may have come about due to the fact that testing activities are less 'firm-specific' and thus more susceptible to being performed outside the firm. Mowery noted that

> as firms grow in size and complexity, then, the more complex, riskier research projects, not readily obtainable via the market, should form the core of the growing in-house research activities of the firm.[44]

The Robert W. Hunt Company was a testing company founded in 1888: Robert Hunt had a deep

> . . . conviction of the value of inspections and tests to both manufacturer and purchaser and of his belief that the testing could be done more efficiently and economically by a company of impartial engineers organized to represent many purchasers.[45]

Yet the Hunt lab, as well as other independent testing labs, participated in various research efforts to improve steel rail, moving from testing to engage in projects more commonly viewed as industrial research (See Chapters 3 and 4, below).

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[43]Lewis, "Industrial Research and Development," p. 622. Abernathy and Utterback corroborate this notion: a firm's industrial research agenda changes as a product or process attains increasing standardization. See Abernathy and Utterback, "Patterns of Industrial Innovation," pp. 45-46.

[44]Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing, 1899-1945," p. 248. Mowery's examination of the activities of three independent research labs--the Mellon Institute, Arthur D. Little, Inc., and the Battelle Institute--indicated that most projects undertaken by these independent labs for manufacturing firms involved simple chemical or metallurgical analysis.

[45]Bartlett, "The Development of Industrial Research in the United States," p. 74.

Section 4. The Transition from Rule-of-Thumb to Science

Testing was an integral part of the transition from rule-of-thumb to science in American industry. Before scientific methods and scientifically trained personnel became generally accepted in industry, products and processes were tested by "practical men," using "rule-of-thumb" guides.[46] The "practical men" were leery of scientists who had little practical experience with manufacturing.[47] Industrial scientists

[46] Thorstein Veblen observed that early industrial methods, even in a 'science-based' industry like chemistry, had "on the whole been a matter of chemical rule-of-thumb rather than of chemical science, . . . of general information and common notoriety rather than exact and calculable processes worked out by detailed experimentation and computation in the chemical laboratories." See "The Technology of Physics and Chemistry," in Absentee Ownership and Business Enterprise in Recent Times (New York: The Viking Press, Inc., 1923, 4th printing, 1954), p. 259.

[47] Charles MacDowell of Armour Fertilizer Company recounted that, in the early days, chemists and engineers were occasionally called in to examine their products or processes, but the practical men jealously guarded their prerogatives and "felt that the scientific man was more or less of a menace or a nuisance. They were sure that their own work was one requiring personal knack and know-how--like good cooking--rather than science." But top management of Armour became interested in taking a more systematic approach to some of the firm's methods, and established a chemical lab. The lab was given a few early assignments to investigate ways to improve the quality of some specific goods produced by Armour; after successes in these small efforts, the lab was given charge of developing standards for all of the firm's medicinal products. However, several departments of the firm remained unconvinced of the efficacy of chemical investigation in their areas; "their processes [were] deep secrets known only to the superintendent of the department and his assistant; they resented bitterly any attempt upon the part of the laboratory to interfere with their methods, or to attempt to investigate their processes. They soon found, however, that the chemist was particularly valuable to them in giving advice that their raw materials purchased were of standard purity." See "The Chemist in the Packing and Allied Industries," Chemical Age, June 1921, pp. 217-18.

first had to overcome the attitudes of "practical men" in order to expand the scope of scientific activities in industry.[48]

Early industrial testing activities increasingly brought scientists into industrial settings and thus played a crucial role in the transition from rule-of-thumb to scientific methods.[49] In fact, many of the first industrial research successes originated in the early testing activities of industrial engineers and scientists, as defective inputs were identified or better materials were found. These first industrial successes sparked further, and more deliberate, efforts to improve materials. As firms strove to attain more uniform results in their manufacturing processes and to lower costs, they realized the need to develop better methods of testing and measurement and began to hire scientifically-educated people to use scientific methods.[50] Even though the initial

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[48]Beer and Lewis observed that the tradition of trade secrecy in industry conflicted with scientists' orientation toward sharing and disseminating the results of their work, and that industrial scientists often represented a "potentially antagonizing influence with regard to the working force." See "Aspects of the Professionalization of Science," Daedalus, Fall 1963, p. 765. Bartlett acknowledged that many of those among the ranks of corporate management held suspicions toward science's "impractical dreamer [who] . . . belonged in the university where he would not upset the methods that had worked for many years." See "The Development of Industrial Research in the United States," p. 24.

[49]Rosenberg asserts that, in the late nineteenth century, the new technology involved in the mass production factory system enabled continuous advancement in processes and product, and made the system amenable to examination and improvement by systematic use of scientific principles and scientific analysis. The major change involved, not so much a conscious application of science to create new technology but, rather, an increase in the amount of scientific knowledge available, helping to accelerate the acquisition of technological knowledge. See Perspectives in Technology, pp. 133, 143.

[50]Lewis, "Industrial Research and Development," p. 621.

functions of these early industrial scientists were restricted to testing and sampling,

> [i]t was not long, before these chemists, with their special training, substituted scientific methods for rule-of-thumb and, as a result, not only accelerated the improvement of existing processes but also utilized waste products and created new products.[51]

Yet the transition from rule-of-thumb to science was a slow process, beginning around the Civil War and only being completed over the first three decades of this century. In the last half of the nineteenth century, a few manufacturing firms hired chemists to resolve specific technical problems in their manufacturing operations; yet these early industrial scientists were largely engaged in "ancillary roles in what was still a largely empirical technology."[52] Although the number of industrial scientists increased in the late nineteenth century, in 1900 there were still only 276 chemists employed on a full-time basis in the chemicals industry.[53] According to J. S. Unger of Carnegie Steel's industrial research lab, as of 1900 industrial research was not performed by individuals specially hired for the work but by a variety of people--

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[51] Bartlett, "The Development of Industrial Research in the United States," p. 25.

[52] Kendall A. Birr, "Science in American Industry," in David D. Van Tassel and Michael G. Hall, eds., Science and Society in the United States (Homewood, Illinois: The Dorsey Press, 1966), p. 41.

[53] Rae asserts that the number of "academically educated" engineers outnumbered the number of "self-taught, trained-on-the-job products of earlier years" by the 1880s. See Rae, "The Application of Science to Industry," p. 252. See also Galambos, "The American Economy and the Reorganization of Knowledge," pp. 269, 272.

the chemist, the engineer, or the departmental superintendent.[54] Through the end of the nineteenth century, the honored place in innovation was still awarded to the "untutored but ingenious gadgeteer."[55]

Scientific methods slowly began to achieve dominance over the first few decades of the twentieth century. During the 1910s, according to Frank Jewett of AT&T, the industrial research lab was still regarded by many firms as an expense department, or in some cases, contained within, and actually subordinated to, a larger manufacturing or engineering department, "struggling to evolve and to prove its worth."[56] By World War I, industrial research in the U. S. was still limited and the "spell of 'cut-and-try' and the national faith in the inspired gadgeteer showed an astonishing ability to survive."[57] During the 1920s large numbers of business executives began to recognize the contribution that scientists could make to industry.[58] By 1928, according to Charles Stine of du Pont, scientific methods were becoming

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[54] J. S. Unger, "Some Practical Views of Research," in American Society for Testing Materials, Topical Discussion on Cooperation in Industrial Research (Philadelphia: American Society for Testing Materials, 1918), p.58.

[55] "Until late in the nineteenth century, only a few industries could use scientific techniques or cared about using them." See Rae, "The Application of Science to Industry," pp. 249-50.

[56] Frank B. Jewett, "Industrial Research: What it is, its place in modern industrial technology, the opportunities it offers," Frank A. Howard Lecture, February 11, 1948, p. 9.

[57] Rae, "The Application of Science to Industry," p. 264.

[58] Charles M. A. Stine, "Chemical Research: A Factor of Prime Importance in American Industry," reprint from Journal of Chemical Education, December 1932, p. 2033.

more dominant and only the "exceptional plant . . . was being run on the basis of rule-of-thumb methods."[59] The transition had occurred slowly over the previous three decades:

> It is easy to recall when the practical man and the scientifically trained man looked askance at one another,--the one acknowledging that the practical man knew nothing and worked entirely by rule-of-thumb; the other, that the laboratory worker was so foolishly impractical in his ideas about manufacturing operations as to incur, at best, nothing more than a tolerant commiseration from the plant man.[60]

By the 1930s industrial science had largely achieved dominance over rule-of-thumb procedures.[61]

Section 5. Cooperative Industrial Research

Industrial testing was also integral to early cooperative industrial research efforts. There has been much recent discussion of cooperative research in light of the technology gap between the U. S. and Japan. Robert Solow recently declared that

> undeveloped cooperative relationships between individuals and between organizations stand out in our industry studies as obstacles to technological innovation and the improvement of industrial performance.[62]

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[59]Charles M. A. Stine, "Chemical Engineering in Modern Industry," prepared for the joint meeting of the American Institute of Chemical Engineering and the Institution of Chemical Engineers, August, 1928, p. 4.

[60]Stine, "Chemical Engineering in Modern Industry," p. 8.

[61]Maurice Holland and W. Spraragen, Research in Hard Times (Washington, D. C.: Division of Engineering and Industrial Research, National Research Council, 1933), pp. 11-12.

[62]Quoted in Thomas Jorde and David Teece, "Innovation and Cooperation: Implications for Competition and Antitrust," Journal of Economic Perspectives, Summer 1990, p. 75.

Much attention is currently being directed to the kinds of cooperative research arrangements used by Japanese and German industry in view of the possibility that such cooperative efforts have promoted these countries' success in high-technology industries.[13]

There are several potential benefits from cooperative industrial research. Duplication of effort when many firms individually pursue the same research goals is eliminated.[14] The resources devoted to basic scientific research may be increased if firms individually invest too little in such research.[15] Market failures that arise from non-cooperative

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[13]Ryuhei Wakasugi gives a variety of reasons for the success of cooperative research in Japan: common technological goals; use of cooperative research as a complement to in-house industrial research; and long-term benefits from participation, including information about their rivals' storehouse of standard technological knowledge and R&D strategies and capabilities. There seems to be some evidence that cooperative research has been used more often for basic research or non-firm-specific research, although some Japanese firms have cooperated in applied industrial research. See "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," in Arnold Heertje and Mark Perlman, Evolving Technology and Market Structure (Ann Arbor, Michigan: The University of Michigan Press, 1990), pp. 214-15, 224-25.

[14]However, Mansfield notes that not all duplicative efforts are necessarily wasteful. When no consensus exists regarding the best way to proceed, it may be useful to pursue parallel efforts: "Parallel efforts may produce results more quickly and more cheaply than attempting in advance to choose the optimal approach and concentrating all one's efforts on pursuing it." See The Economics of Technological Change, p. 71.

[15]As Nelson asserts, "under our present economic structure the social benefits of basic research are not adequately reflected in opportunities for private profits." See "The Simple Economics of Basic Scientific Research," in Nathan Rosenberg, The Economics of Technological Change (Middlesex, England: Penguin Books, Ltd., 1971), p. 160. In 1961, most basic research was funded by the federal government: see Nelson et al, Technology, Economic Growth, and Public Policy, pp. 59-61. Mansfield agrees that firms will "almost certainly invest less than is socially optimal in basic research. This is because the results of such research are unpredictable and usually of little direct value to the firm supporting the research, although potentially of

industrial research efforts are eliminated.[46] Research costs for any one firm are reduced, enabling smaller firms to obtain access to research results and all firms to reduce research risks.[47]

There are some problems with this Panglossian view of cooperative industrial research. First, the industrial science produced through cooperative efforts is not transferred costlessly to participating firms: sufficient in-house expertise and other resources is required in order to utilize research results; and therefore cooperative research may function best as a complement to, and not as a substitute for, in-house research. Second, firms may fear that exploitation of revolutionary innovations will make existing technology obsolescent and thus may steer the cooperative research agenda away from such research. Third, if firms in a given industry rely heavily on cooperative research, the number and diversity of research projects may decline. Fourth, in a highly competitive industry, profits from any new products and processes resulting from

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great value to society as a whole." See Mansfield, The Economics of Technological Change, p. 187.

[46]These market failures include R&D spillovers, free-riders, excessive licensing costs, and asymmetric information, all due to the fact that social incentives for industrial research exceed private incentives. See Michael L. Katz, "An analysis of cooperative research and development," Rand Journal of Economics, Winter 1986, pp. 537-38. Cooperative industrial research provides an institutional mechanism to avoid such market failures as opportunism and asymmetric information. Nelson notes that knowledge should be shared "where it is of high cost not to do so, and the cost in terms of diminished incentives is small. Do the work cooperatively, or fund it publicly, and make public those aspects of technology where the advantages of open access are greatest, or where proprietary claims are most difficult to police." See "Institutions supporting technical change in the United States," in Dosi et al, eds., Technical Change and Economic Theory (London: Pinter Publishers, 1988), p. 315.

[47]Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, pp. 240-41.

cooperative research might be dissipated; under such conditions, firms may collude, under the aegis of a cooperative industrial research mechanism, to hinder research.[68]

Such potential benefits and costs of cooperative industrial research are based on the institutional forms typically assumed to apply to cooperative industrial research.[69] But different institutional arrangements have been proposed to avoid the potential pitfalls of typical cooperative research forms and still provide some of the benefits--for example, more flexible arrangements with respect to sharing costs and results and ways to enhance spillover of research results.[70] In particular, technical and professional societies can serve as useful institutions to share technological information and to "facilitate the spread of certain kinds of information among rivals," because the professional meetings and journals of such societies speed dissemination of technology. Through technical associations, competing firms could share costs and "have certain kinds of research carried out

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[68]This discussion is drawn from Katz, "An analysis of cooperative research and development," p. 529; and Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, pp. 240-41.

[69]One typical institutional form assumed to apply to cooperative industrial research is the research consortia, where member firms share in funding the research venture and the research results. Yet the number of real-world research joint ventures has been small, as real world research joint ventures hold significant problems for individual firms: for example, how to establish and monitor contributions by member firms, and how to allocate the benefits fairly and efficiently. See Sanford V. Berg et al, Joint Venture Strategies and Corporate Innovation (Cambridge, Massachusetts: Oelgeschlager, Gunn & Hain, Publishers, Inc., 1982), pp. 11, 70-71.

[70]Katz, "An analysis of cooperative research and development," p. 542.

cooperatively where the results are difficult to keep proprietary, or where it would be disadvantageous to the group as a whole to do so."[71]

Collaboration in research is especially useful in cases where firms possess complementary skills and assets that make collaboration productive for both parties.[72] Such cooperative research should not be limited to horizontal arrangements between firms producing similar products or using similar processes, but can include vertical arrangements between producing and consuming firms. It is one of the major theses of this dissertation that cooperative industrial research efforts in steel relied on institutional forms in which consuming firms worked to improve the steel products used by their firms. Customers may be the

> . . . most frequent source of projects originating outside the research laboratory. In the nature of things, it seems evident that these outside sources are most likely to offer suggestions that lead to research on improving current products and processes. Customers typically tend to be interested in improvements in materials or equipment presently in use.[73]

There is some evidence that seventy-five percent of commercially successful industrial good innovation projects come in response to a

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[71]These points are raised in Nelson, "Institutions supporting technical change in the United States," pp. 318-319.

[72]David J. Teece, "Technological change and the nature of the firm," in Dosi et al, eds., Technical Change and Economic Theory (London: Pinter Publishers, 1988), pp. 278-79.

[73]Hamberg, "Invention in the Industrial Research Laboratory," p. 103.

consumers' need for an innovation, rather than on the basis of a perceived "technological opportunity."[14]

Lundvall has developed an model of cooperative industrial research that assigns an explicit role to the user and thus fits well with the alternative definition of industrial research being developed in this dissertation.[15] The producing firm interacts with consuming firms to identify their concerns, and in so doing, establishes "technological interdependencies"[16] with consuming firms that induce further innovation on the part of the producing firm. Consuming firms interact with producing firms for several reasons: to obtain information about new products; to involve producers in solving their technical problems; and to compile information about the reliability of producers.[17] Lundvall notes that innovative efforts of producing firms may deviate from the needs of consuming firms when producers dominate because of their financial or technical strength. In such cases consuming firms might find it useful to organize in order to develop an effective

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[14]Eric von Hippel, "The dominant role of users in the scientific instrument innovation process," Research Policy, 1976, p. 213.

[15]Support for Lundvall's interactive, user-based, cooperative industrial research model comes from Nelson, who observes that a recent survey of a number of firms reveals that the "contribution of upstream firms [to the innovation process] was strongly positively correlated with the reported contribution of professional and technical societies." See "Institutions supporting technical change in the United States," p. 317.

[16]Lundvall, "Innovation as an interactive process," p. 352.

[17]Lundvall, "Innovation as an interactive process," p. 353. Disloyalty and cheating may also be a part of the relationship between producing and consuming firms. There may be less than full disclosure of information if there is a lack of trust between these two sides.

counter-weight to producing firms.[78] Lundvall's model relies on institutional innovation as well:

> [i]n a period characterized by radical change in the technological basis of the economy, established organizational and institutional patterns might prove to be important obstacles to the exploitation of the full potential of new technology. In such a period, social innovations might become more important for the wealth of nations than technical innovations.[79]

The early twentieth century witnessed several such cooperative industrial research efforts, with several manufacturers' and technical associations engaged in research work "for the common benefit of their members."[80] World War I brought an increase in the extent of cooperative industrial research through institutions such as the National Research Council, established to coordinate the nation's efforts toward the war effort.[81] For the first time, scientists from industry, government, and universities worked together on large scale,[82]

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[78]Lundvall, "Innovation as an interactive process," p. 358. Government might also establish organizations to intermediate between producers and users, and to pool information to stimulate the production and diffusion of innovations.

[79]Lundvall, "Innovation as an interactive process," p. 366. In fact, "[w]hat separates pure science from technology is primarily the institutional framework. Science will, typically, be produced in universities according to an academic 'mode of behaviour', while technology primarily will be produced in private firms according to a profit-oriented 'mode of behaviour'" (p. 364).

[80]Fleming, Industrial Research in the United States of America, pp. 20, 32-33.

[81]This was a critical time when the U.S. could not obtain the chemicals, dyes, medicines, and glass from Germany; a "united effort upon the part of scientists, industrialists, and Government officials soon relieved the situation." See Bartlett, "The Development of Industrial Research in the United States," p. 35.

[82]Rae, "The Application of Science to Industry," p. 265.

resulting in a "a widespread conviction that industrial research was essential to industrial progress."[13] The trend continued after the war. Small firms in some industries continued to use trade associations to initiate their industrial research efforts, while independent commercial labs were established to help small firms in other industries. Even large firms found cooperative research efforts useful.[14] By 1940, there were three main forms of cooperative industrial research in existence: ongoing research activities by technical societies and trade associations (many firms used the research facilities of their trade associations as their primary research facilities[15]); interfirm efforts to develop new products or processes; and cooperative efforts linking universities, government agencies, and private consulting laboratories (for example, the Bureau of Standards worked with firms in many industries[16]), usually investigating questions of fundamental science.[17] Cooperative

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[13]Kendall Birr, "Industrial Research Laboratories," in Nathan Reingold, ed., The Sciences in the American Context: New Perspectives (Washington, D. C.: Smithsonian Institution Press, 1979), p. 199.

[14]Notably, large firms in the petroleum, paper, textile, lumber, leather, cement, and paint industries. See Lewis, "Industrial Research and Development," p. 630.

[15]National Association of Manufacturers Patents and Research Committee, Trends in Industrial Research and Patent Practices, p. 5. This was particularly true for firms in the following industries--lumber, food, stone, clay and glass, and printing.

[16]Fleming, Industrial Research in the United States of America, pp. 32-33.

[17]C. G. Worthington, "Coordination between Industries in Industrial Research," in National Research Council, Research--A National Resource, vol. II (Washington, D. C., National Research Council, 1940), p. 85. Mees also identified three existing forms of cooperative industrial research laboratories: consulting research labs taking work on a contractual basis, cooperative research labs maintained by trade associations, and technical research institutes. See C. E. Kenneth Mees and John A.

industrial research was organized under a "diversity of institutional mechanisms."

Many of the participants in these early cooperative industrial research efforts argued that industry would benefit greatly. James Angell of the National Research Council asserted that cooperative research was essential to bring together persons with skills in "convergent or overlapping" fields, especially for smaller firms. In his view, cooperative research could eliminate the problem of duplication of effort:

> . . . men . . . working on common problems, investing time and energy which might have been expended to far better effect could they have been brought in touch with one another and have learned each what the other had to give in the way of knowledge already ascertained.

Frank Jewett of AT&T argued that small firms particularly required cooperative research. Independent consulting engineer A. D. Little proposed a grand scheme for cooperative industrial research:

> . . . a permanent, coherent and progressively effective form of organization for the promotion and coordination of research. . . . in the shape of a great foundation closely affiliated with the government, the universities, the technical societies and the industries, which shall have its broad policies directed by a board, wholly divorced from politics, yet intimately in touch with the trend of science

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Leermakers, The Organization of Industrial Scientific Research (New York: McGraw-Hill Book Company, Inc., 1950), p. 85.

Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 24.

James Rowland Angell, "The Development of Research in the United States," National Research Council, Reprint and Circular Series, # 6, pp. 8-12.

Frank B. Jewett, "Industrial Research," National Research Council, Reprint and Circular Series of the National Research Council, No. 4, p. 13.

> and the needs of industry, and which shall depend for the execution of its plans upon a permanent executive and well-paid scientific staff.[11]

Yet, despite many historical precedents for cooperative research, most cooperative research efforts in the U. S. are less than ten years old today.[12] The institutional structure for industrial research

> clearly depends on the technological and economic environment of that research system. . . . new structures for the performance of research, including domestic and international cooperative research, now are emerging in response to change in the environment.[13]

Therefore, it is important to consider these "institutional factors as an influence on the pace of diffusion (and) . . . in improving the environment for innovation."[14] The historical examples of cooperative industrial research in the manufacture and processing of steel to be presented in this dissertation shed light on some useful institutional forms for cooperative industrial research.

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[11]Arthur D. Little, "Organization of Industrial Research," in American Society for Testing Materials, Topical Discussion on Cooperation in Industrial Research (Philadelphia: American Society for Testing Materials, 1918), p. 21.

[12]Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 238.

[13]Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 4.

[14]Rosenberg, Inside the Black Box, p. 20. And such an approach is in keeping with Chandler's organizational approach to business and economic history, as a way to capture the crucial "importance of organizational arrangements in the effective application of the findings of science to the improvement of industrial productivity." See Chandler, "From Industrial Laboratories to Departments of Research and Development," p. 60.

Section 6. Conclusion

Examination of the backward linkages to industrial research in the manufacture and processing of steel requires use of an alternative understanding of industrial research. Such an alternative understanding is founded on a multidirectional process of innovation and integrates some frequently unaddressed issues in industrial research--industrial testing, the transition from rule-of-thumb to science, and cooperative research. Such an alternative understanding allows scrutiny for the first time of the incremental, cumulative innovations that followed on the heels of major innovations in steel products and processes that have previously been neglected. Such an alternative understanding will be used in the following chapters to screen the innovation in steel products and processes between 1870 and 1930.

CHAPTER 2

THE STEEL INDUSTRY IN THE UNITED STATES BEFORE 1900

Section 1. Technological Change and Industrial Organization in the Steel Industry Before 1900

The introduction of the Bessemer steel process served as a major impetus to rapid expansion of the U.S. steel industry after the Civil War.[1] Over the next three decades, the industry experienced vigorous competition which ended only in 1900 with the formation of a stable oligopoly dominated by U.S. Steel. These major changes in the technology and industrial organization of the steel industry help to explain the low levels of industrial research in 1900.

Increased demand for imported Bessemer steel rails by U.S. railroads after the Civil War prompted U.S. firms to install Bessemer converters and to begin to roll Bessemer steel rails. The first experimental Bessemer steel rails were produced at the North Chicago Rolling Mill in 1865 while the first steel rails made "in the way of regular business" were produced at the Cambria Iron Works in 1867.[2]

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[1]The Bessemer process reduced the costs of refining raw iron ore into steel and made large-scale steel production economical, and thus served as a major impetus for the transition from iron to steel after 1850 in the United States. See Rosenberg, Inside the Black Box, p. 90; and Peter Temin, Iron and Steel Production in Nineteenth Century America (Cambridge, Massachusetts: The M.I.T. Press, 1964), p. 4.

[2]Victor H. Clark, History of Manufactures in the United States, Vol. II (New York: McGraw Hill Book Co., Inc., 1929), pp. 74-77. Over the next few years the Pennsylvania Steel Company and the Troy Steel Works also began to roll steel rails. In 1873, two new steel rail works,

Yet rail users were still hesitant about steel rails and entry into the new steel industry was slow. Early steel producers faced a number of obstacles to rapid diffusion of Bessemer steel. Chief among these was the fact that early Bessemer steel was not uniform in quality and thus unreliable in performance:

> . . . experts argued that though Bessemer steel would last longer than iron, 'it is comparatively easy to make the toughest steel brittle by cold hammering.' An iron rail would retain its fibrous character until so worn as to require replacement, but a steel rail might . . . be in an unsafe condition internally while presenting a fair external appearance.[3]

Nonetheless, favorable reports from early steel rail users led to increased demand for Bessemer steel rails. The biggest obstacle for U.S. steel producing firms soon became to increase output to meet the rapidly increasing demand. Consequently, during the last three decades of the nineteenth century, most technological change in Bessemer steel production was directed at increasing both the scale and the speed of steel production, resulting in increased throughput and reduced steel prices. The most famous of these was Carnegie's use of hotter blasts under higher pressure to obtain more output from every furnace run--a

later to become the most prominent steel rail producers, were established: the Bethlehem Iron Company and Carnegie's Edgar Thompson Steel Works. See also William H. Sellew, Steel Rails (New York: D. Van Nostrand Co., 1913), p. 4.

[3]Clark, History of Manufactures in the United States, Vol. II, pp. 70-71, 78. Other obstacles included: the requirement that the iron ore used in the process be low in phosphorus; the larger initial investments and longer pay-back time for investments in steel production; and the increased waste. See also Temin, Iron and Steel Production in Nineteenth Century America, pp. 169-174.

technique referred to as "hard driving."[4] Other noteworthy innovations included the large Player stove, larger blast furnaces, changes in plant layout and fuel to reduce labor costs, and the three-high rolling mill.[5] The net result for steel producing firms was increased output, reduced labor costs, and some improvement in steel quality and uniformity--this last, however, was an indirect effect of these innovations and not an explicit goal of steel producing firms.

Another series of changes that helped to increase throughput and reduce price in the emerging Bessemer steel industry was vertical integration of steel works.[6] As the minimum efficient scale of Bessemer

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[4]Carnegie's Edgar Thompson Works pioneered this technique in 1881 and doubled output without altering the plant. See Temin, Iron and Steel Production in Nineteenth Century America, p. 163.

[5]See Clark, History of Manufactures in the United States, Vol. II, pp. 77-79, 205. Other innovations included: increasing the number of heats; using larger and more converters in a single plant; using removable bottoms for Bessemer converters; using better refractory lining in the furnaces; using hydraulic crane systems to move ingots; using two-high reversing mills; rolling rails directly from the ingot without shearing or reheating the bloom; using coke for the smelting fuel; using by-product coke and charcoal ovens; and moving to water cooling and dry-air blasts. The trend in the use of larger and larger furnaces became a competition for a time--the famous Lucy furnace, built at Pittsburgh in 1872, was the largest furnace to date, 75 feet high by 20 feet in diameter, and was built to ensure a supply of pig iron for the Pittsburgh steel works. It produced the record output to that date--475 tons of Bessemer steel per week. When Carnegie's firm, the Edgar Thompson Steel Company, began to produce Bessemer steel in 1873, Carnegie built the famous Isabella furnace to rival the Lucy furnace in output levels. In 1873 Cambria also built two furnaces of the same design.

[6]In the pre-Civil War iron industry, blast furnaces, forges, and rolling mills were usually separate, unintegrated producing units. However, a few early iron works integrated the stages of iron producing, primarily iron rail producers: the rolling mills used to produce rails had larger capacity than other kinds of rolling mills and could capture great economies by guaranteeing a steady flow of pig iron from the blast furnaces to the rail mills. By 1860, the four largest iron producers in the U. S. were integrated iron rail mills: Pennsylvania Iron

steel plants increased, steel producing firms found it useful to integrate downstream to raw material and pig iron sources to keep their large furnaces and rail mills running "steady and full."[7]

Thus, technological change in Bessemer steel production and vertical integration of steel works combined to increase the average size and output of a Bessemer steel firm.[8] Rapid expansion in rail

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Works (originally the Montour Iron Works), Cambria Iron Works, the Phoenix Iron Company, and the Trenton Iron Company. However, vertical integration did not really spread until after the Civil War with the diffusion of the Bessemer process and the emergence of the steel industry. See Temin, Iron and Steel Production in Nineteenth Century America, pp. 106-110.

[7]There were several motives for vertical integration with the Bessemer process. First, producers could use the heat generated by the large scale chemical reactions in the blast furnaces in other production stages by integrating several stages of operation in one continuous production line. Second, due to the precise chemical control required for iron ore inputs, it was useful to integrate backward to the sources of iron ore supply and to the blast furnaces smelting the raw iron ore. Third, the large steel rail rolling mills required steady output from two, or even three, blast furnaces, to run at full capacity, i.e., run "steady and full." Finally, the average steel producing firm--especially steel rail producers--used more complex and more expensive technology to roll the more complex steel rail shapes; these firms had very high fixed costs, and found it necessary to generate a large and steady output to generate large and steady revenues: "[t]he size of the plant required thus implied both large scale and limited entry, while large scale provided the impetus toward integration." See Temin, Iron and Steel Production in Nineteenth Century America, pp. 2-3, 112-113, 155; and also Alfred Chandler, Scale and Scope (Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 1990), pp. 128.

[8]Both capacity and capital requirements for steel production increased. In 1880, the average capacity of an iron rolling mill was only 12,000 tons per year while the average capacity of a Bessemer steel plant was 114,000 tons per year. Between 1870 and 1900 the average output for an individual steel works increased from 3,000 tons to 23,000 tons and the average investment for an individual steel works increased from $150,000 to $1 million. The largest operations exceeded these averages: by 1894, the Carnegie works and Illinois Steel, the two largest vertically integrated steel producers in the late nineteenth century U. S., each produced approximately 2 million tons per year: "the large size of the required capital created a concentrated subindustry." See Temin, Iron and Steel Production in Nineteenth Century America, pp. 106, 154,

production continued through the 1870s and 1880s and rail prices declined steadily.[9] A concentrated industry of large-scale, vertically-integrated steel producing firms was evolving in these closing decades of the nineteenth century in place of the earlier small-scale, non-integrated iron producing firms, with rails as their major product.[10]

The largest steel producers--not coincidentally, those using the most modern plant and techniques--continued to produce record outputs and were able to further reduce production costs.[11] Falling prices and excess capacity in the industry led to a "struggle for survival of the fittest"[12] over the last three decades of the nineteenth century, in

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166-68.

[9]Rail output continued to increase through the last years of the nineteenth century: "the market for rails was the barometer which measured the prosperity or depression of iron and steel manufacturing." See Clark, History of Manufactures in the United States, Vol. II, p. 73. The falling prices for steel promoted "an immense increase in its use--its widespread substitution for wood and iron--for example in machinery and rails." See Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 22.

[10]In 1887, fourteen steel producing firms accounted for ninety percent of total rail output. The Bessemer steel industry was largely devoted to the production of rails: during the first great expansion phase of the steel industry, most of the steel produced was used for rail production. See Naomi Lamoreaux, The Great Merger Movement in American History (Cambridge: Cambridge University Press, 1989), p. 77; and Temin, Iron and Steel Production in Nineteenth Century America, p. 221.

[11]Clark, History of Manufactures in the United States, Vol. II, p. 331.

[12]During the 1870s, most steel producers attempted to run their operations at full capacity, and total output of rails exceeded demand. As a result, the price of steel rails fell: from 1873 to 1877 steel rail prices fell from $120 per ton to $40 per ton and by 1883 fell below $40 per ton. Prices continued to fall for the remainder of the century. The price reduction had the effect of inducing the substitution of steel for iron rails and for other iron products. See Clark, History of Manufactures in the United States, Vol. II, pp. 221, 330.

which the structure of the industry changed from a monopolistically competitive industry to a dominant-firm oligopoly. During the 1870s and 1880s, steel producing firms attempted to use loose combinations to restrict output and restore price with little success.[13] An increasing number of firms turned to horizontal and vertical integration to shield themselves from market pressures: the two largest--Carnegie Steel and Illinois Steel--embarked on such expansion programs during the 1880s and 1890s.[14] The Illinois Steel combination exemplified the economic

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[13]A number of pig-iron producers met in 1874 to discuss ways of reducing output, but they could not reach an agreement. One obstacle to these agreements was the fact that the largest producers used the most modern technology and held a considerable economic advantage over smaller producers using older technology. Even with low prices, the large producers could make profits. The early years of the Long Depression fostered many unsuccessful attempts at combination--primarily in the form of pools. See Clark, History of Manufactures in the United States, Vol. II, p. 223; and Temin, Iron and Steel Production in Nineteenth Century America, p. 208.

[14]In 1875 Carnegie owned the Edgar Thompson works with a capacity of 5,000 tons of Bessemer pigs/month. By 1890 Carnegie owned the Edgar Thompson Steel Works, the Duquesne Steel Works, the Homestead Steel Works, the Union Mills, the Beaver Falls Mills, the Lucy Furnaces, the Keystone Bridge Company, and a number of subsidiary coal mines, coke ovens, and iron mines. Illinois Steel went through a similar expansion. In 1875 the North Chicago works of the future Illinois Steel was already producing 34,000 tons of pig iron, 36,000 tons of steel, and 22,000 tons of iron shapes in 1875. It initiated a process of vertical integration in the 1880s, acquiring four blast furnaces and a new plant, and by 1888 the product of all of its plants exceeded 1 million tons. In 1889, a giant consolidation of steel interests occurred in Chicago: the North Chicago Works combined with the Union Iron and Steel Company of Chicago and the Joliet Works to form the Illinois Steel Company. The new corporation--Illinois Steel--owned five plants, fourteen blast furnaces, four Bessemer steel plants, coal lands, 1,150 coke ovens, a railway, and mills for rails, rods, plates and structural shapes and was "believed to have a larger output than any other steel company in the world . . . . But the Carnegie Company was a close competitor, and when its projected plant enlargements were completed it was expected slightly to outdistance its western rival." These two firms formed the core of U.S. Steel in 1901. Other large steel producers used vertical integration of their production processes to shield their operations--for example, Pennsylvania Steel in 1875, Lackawanna Steel in

advantages held by these large horizontally- and vertically-integrated combinations:

> There would be a saving in the cost of management, in the distribution and allotment of raw materials, and above all in diversifying and specializing the output of the new company's plants, thus avoiding in a degree the previous overstocking of the market with particular forms of steel and consequent periods of idleness.[15]

The largest steel producers were able to exploit their advantages by increased throughput; in fact, running production lines "steady and full" was a strategy available only to the large horizontally- and vertically-integrated steel producers.[16] By the end of the century, the largest firms dominated the market for steel rails, and they used their economic advantage to drive smaller producers out of the industry.[17]

1874, and Bethlehem Steel in 1877. See Clark, History of Manufactures in the United States, Vol. II, pp. 232-37.

[15]Clark, History of Manufactures in the United States, Vol. II, p. 238.

[16]Increasing throughput required more than increasing the scale of operation for a steel production line; it required a concomitant ability to keep the production line running 'steady and full.' In other words, the increased output of blast furnaces had to be quickly pushed through the rail mills to be profitable to producers, providing new impetus for integration of furnaces with mills and giving increased economic power to producers like Carnegie and Illinois Steel who were first to fully exploit the economies of scale, scope and speed in steel production and thus to gain a competitive edge on their steel rivals. Many other large steel producers were able to use vertical integration of their production processes to shield their operations: Pennsylvania Steel, Lackawanna Steel, and Bethlehem Steel. See Chandler, Scale and Scope, p. 128; and Clark, History of Manufactures in the United States, Vol. II, pp. 232-33, 333.

[17]"The rail business was controlled during most of this period by a pool, which fixed prices and allotted output to its constituent firms. This organization, which dated back to 1885, had a stormy career and was temporarily terminated on various occasions. Prior to the organization of the United States Steel Corporation it was dominated by the Carnegie Steel Company and the Illinois Steel Company, which usually worked under an agreement that made them virtually a pool

The competitive pressures were resolved in 1901 with the formation of the steel trust. Thereafter, the industry became a stable dominant-firm oligopoly, with U.S. Steel controlling sixty percent of the market for steel rails and sixty-six percent of the market for steel ingots.[18] U.S. Steel exercised price leadership and advocated conservative price policies, leading to stability in steel rail prices for many years after 1901.[19]

Bessemer steel rails remained the major product of the steel industry through 1900.[20] Demand for rails continued to increase sufficiently to absorb the output of Bessemer steel rail producers. Thus there was little pecuniary incentive for any Bessemer steel producing firm to improve steel quality or to innovate new steels to develop potential markets for other steel products. And the commanding market share of U.S. Steel in 1901 seems to have weakened any pecuniary incentive that smaller steel producing firms may have had to compete

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within a pool. When they fell out the pool was disrupted, as happened in 1897." Attempts to form a rail makers' pool required cooperation from both of these producers to succeed. See Clark, History of Manufactures in the United States, Vol. III, p. 118; and also Lamoreaux, The Great Merger Movement in American History, pp. 78-85.

[18]And equally large shares of the markets for other major steel products--structural shapes, plates and sheets, rods, iron ore, and nails. See Chandler, Scale and Scope, p. 138. See also Gertrude Schroeder, The Growth of Major Steel Companies (Baltimore: The Johns Hopkins Press, 1953), pp. 37-38.

[19]Clark, History of Manufactures in the United States, Vol. III, p. 101. There had been complaints prior to 1900 from rail producers that "the rail pool would not let them sell open-hearth rails at the premium they deserved, or that the effects of integration were to lock producers into the existing technology." See also Temin, Iron and Steel Production in Nineteenth Century America, p. 222.

[20]Rosenberg, Perspectives in Technology, p. 202; and Clark, History of Manufactures in the United States, Vol. II, pp. 269-70.

with the dominant firm by using industrial research to create new or improved steel products or processes.

Section 2. The Emergence of Industrial Research in the Steel Industry

In 1880 ninety percent of the steel manufactured in the U. S. was Bessemer steel.[11] The Bessemer process continued to dominate the U.S. steel industry during the last two decades of the nineteenth century. Increased demand for Bessemer steel rails had, over these decades, induced a series of incremental, cumulative, cost-reducing, output-increasing innovations in steel production.

Yet the important point is that organized in-house industrial research by steel-producing firms did not play a large part in these innovations. Rather, these innovations were developed primarily through the efforts of independent inventors or "rule-of-thumb" men--people possessing practical, hands-on knowledge of steel rather than academic training in chemistry or metallurgy.[12] The most prominent nineteenth

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[11]Rosenberg, Inside the Black Box, p. 90.

[12]In so doing, steel producing firms followed the pattern established by their predecessors in the iron industry in the late eighteenth and early nineteenth century: innovations in iron were "based on empirical knowledge rather than on scientific understanding. . . . the general picture of the American iron industry in the early nineteenth century is of one dominated by practical men who frowned on scientific 'theorists.'" See Kendall A. Birr, "Science in American Industry," in David D. Van Tassel and Michael G. Hall, eds., Science and Society in the United States (Homewood, Illinois: The Dorsey Press, 1966), p. 41. Rosenberg agrees that the "spectacular developments in the iron and steel industry beginning in the mid-nineteenth century are a forceful demonstration that the new directions--including the very transformation of the industry from an iron industry into a steel industry--did not originate in advances in new scientific knowledge." See "The Commercial Exploitation of Science by American Industry," p. 27.

century steel innovator exemplified this fact: Henry Bessemer developed his process without any training in "the chemistry of his day,"[13] but was successful almost by accident, because he happened to use a nonphosphoric Swedish charcoal iron particularly suited to his new steel making process. Thus the initial innovation of Bessemer steel, and its subsequent industrial applications did not come about from the application of new science and the work of scientifically-trained researchers but, rather, from the application of old science and the work of practically-trained innovators.[14] As steel gradually displaced iron, innovations continued to be the "work of shrewd empiricists, not of trained scientists."[15]

The nineteenth century innovations were primarily aimed at reducing the cost of steel production. The cheapness of steel made it attractive for use in an increasing variety of industrial products. Yet, because the original Bessemer technology was based on rule-of-thumb technology, and because there was little scientific understanding of the chemical and physical characteristics of Bessemer steel, problems with Bessemer steel quality began to emerge that could not be surmounted with simple rule-of-thumb methods: increasingly, "the lack

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[13]Mowery and Rosenberg, <u>Technology and the Pursuit of Economic Growth</u>, p. 29.

[14]Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 22.

[15]Birr, "Science in American Industry," p. 65.

of chemical knowledge was a serious handicap and often spelled the difference between success and failure of a particular innovation."[16]

Limited scientific analysis of steel was initiated shortly after the Civil War. Early experiments were conducted with British phosphoric and nonphosphoric ores, resulting in development of crude methods for analyzing iron ores. A few early users of Bessemer steel discovered that Bessemer steel became brittle as it aged, and they initiated early industrial research into the possible causes of this phenomenon.

Steel producing firms slowly began to recognize the importance of implementing scientific methods, and, accordingly, in the 1860s, a few firms hired trained chemists and metallurgists to conduct analysis of their raw materials and blast furnace output.[17] In the 1870s steel producing firms initiated more systematic industrial research efforts when industrial scientists began to determine that the Bessemer process required rigid chemical constituents for raw material inputs.[18] Many

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[16]Birr, "Science in American Industry," p. 65. Increasingly, the steel industry "placed a premium on basic chemical knowledge: knowledge . . . of great economic value . . . not only in assuring quality control in manufacturing, but in the selection of the raw materials--the coal and the iron ore--to be employed in the productive process." See Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 29. Even before the introduction of the Bessemer process, quality control of steel was problematic. John Fritz, one of the foremost steel plant engineers of the late nineteenth century, complained that iron producers had also lacked satisfactory methods of chemical analysis and were plagued with quality control problems. See Birr, "Science in American Industry," p. 41; and Rosenberg, Perspectives in Technology, p. 196.

[17]Bartlett, "The Development of Industrial Research in the United States," pp. 27-28.

[18]The chief requirement was that iron ore be free from phosphorus. In fact, the quality of the steel produced by the Bessemer process was extremely sensitive to the chemical composition of the raw material inputs. See Temin, Iron and Steel Production in Nineteenth Century

steel producing firms instituted regular tests of the iron ores used in Bessemer production.[29]

Some steel producing firms established entire in-house testing and research laboratories. One of the first in-house laboratories was established in 1863 to test raw iron ores for Bessemer production at the experimental Bessemer steel works at Wyandotte.[30] The most famous early laboratory was that of Carnegie Steel, which hired its first staff chemist in the 1870s to test raw materials. As Carnegie later noted, the precise chemical knowledge thus gained by his firm was invaluable for pecuniary and quality control purposes: it allowed Carnegie to purchase raw material on the basis of its known chemical content, rather than on the mine owner's reputation--not incidentally, netting considerable savings for Carnegie.[31] Midvale Steel hired two metallurgists in 1872 to assist in the development of the firm's new open-hearth steel production process. Midvale's chief metallurgist William Durfee and assistant

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America, p. 156; and Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 27.

[29]This was useful to steel producers as it helped promote expansion of the steel industry: "the rapid and spectacular developments in the American iron and steel industry would have been impossible but for the work of trained chemists, metallurgists, and engineers. If the industry as a whole has lagged in organized research, it is nevertheless true that some companies began early to make a rational attempt to apply the findings of the chemist to their immediate problems." See Bartlett, "The Development of Industrial Research in the United States," p. 27.

[30]Wyandotte was the first steel works to roll Bessemer steel in the U. S. See Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 28; Clark, History of Manufactures in the United States, Vol. II, p. 70; and Bulletin of the American Iron and Steel Association, November 12, 1884, Vol. 18, p. 291.

[31]Bartlett, "The Development of Industrial Research in the United States," pp. 27-28.

metallurgist Charles Brinley were engaged to conduct analysis of raw materials and maintain record-keeping for all open-hearth heats.[32] Albert Sauveur, one of the most famous turn-of-the-century metallurgists, worked for both Pennsylvania Steel and Illinois Steel in the years before 1900. Sauveur came to Illinois Steel in 1891 and persuaded the plant manager to allow him to pursue his ongoing academic research work into the microstructure of iron and steel.[33]

But only a small number of steel firms established such in-house chemical labs in these early decades of steel production. In addition to those mentioned above, only four other steel producing firms established in-house industrial research labs before 1900. Two were small firms--Granite City Steel and Harrisburg Steel; and two were large firms--Inland Steel and Taylor Wharton Iron and Steel.[34]

A common perception was that testing raw material inputs for the Bessemer process could be just as easily performed by independent testing laboratories as by in-house labs of steel producing firms. A number of independent testing laboratories were also established in

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[32]Rae, "The Application of Science to Industry," p. 259.

[33]This was the pioneering metallurgical work that would later establish him as "one of the world's leading metallographers." But a new general manager came to the South Chicago works in 1897 and abolished Sauveur's metallographic lab in a cost-cutting measure. See Birr, "Science in American Industry," p. 65.

[34]Large firms are considered to be those ranked among the top 500 firms in the United States in 1917; small firms rank below those top 500 firms. See Thomas R. Navin, "The 500 Largest American Industrials in 1917," Business History Review, Vol. XLIV, No. 3 (Autumn 1970), pp. 360-86. The foundation dates for these four labs were as follows: Granite City Steel established its lab in 1895; Harrisburg Steel in 1899; Inland Steel in 1894; and Taylor Wharton Iron and Steel in 1892. See National Research Council, Industrial Research Laboratories of the United States (Washington, D. C.: National Research Council, 1921, 1946).

these decades to provide testing services to steel producing firms. One early testing laboratory was established by the American Iron-Masters in 1866 at Philadelphia "to encourage the development of workable bodies of iron ore and to inform producers of the quantity and quality of the metal they would yield."[35] Another early testing lab was established in 1868 by Rensselaer Polytechnic Institute (RPI) in connection with its assay department and was equipped to handle commercial analyses. George Maynard, RPI chemist, was retained by Alexander Holley, manager of John A. Griswold & Company's Bessemer plant, to analyze samples of ore, pig iron and steel. The RPI lab came to serve a large number of steel producing firms which did not have their own in-house labs:

> . . . During the period from 1868 to 1873 my work as a consulting mining engineer frequently called me to the Lake Champlain iron district and involved the examination and sampling of about all the developed mines and prospects, in hunting for Bessemer ores . . . .
>
> On referring to my record of many hundred analyses during those years, I find that samples of ore, pig iron, slag and steel came from many widely scattered works, which would indicate that chemical laboratories were exceptional in connection with iron and steel works.[36]

Most of the chemists and metallurgists employed by steel producing firms or by independent testing laboratories in the late nineteenth century were primarily concerned with analysis of raw material inputs so important to Bessemer steel producers. While their testing was a departure from rule-of-thumb methods, there was little effort on the part of steel producing firms to improve the quality of output or to develop new products. Instead, research efforts not

[35] Clark, History of Manufactures in the United States, Vol. II, p. 78.

[36] The Iron Age, January 10, 1910, p. 72.

devoted to testing were largely devoted to reducing costs. Among the products of this research were three of great importance: better blowing engines for blast furnaces, improved rolling mills, and development of mass production technology that could produce barbed wire, fences, nails, and springs.[37]

It thus fell to the steel consuming firms to test the steels that they used.[38] Among the steel-consuming firms engaged in this sort of research were electrical equipment manufacturers like General Electric and Westinghouse; automobile manufacturers like General Motors, Ford and Dodge; the Pennsylvania Railroad; and a number of smaller producers of fabricated metal products, transportation equipment, and machinery.[39] Their laboratories began to investigate the steels used by their firms and to specify the physical and chemical characteristics desired. During the years 1880 to 1910 the failure of parts made of Bessemer steel increased (discussed in more detail in Chapters 3 and 4). It was the chemists for steel consuming firms who discovered that the Bessemer process itself added significant impurities to the steel and that

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[37]Frank Sisco, a steel industry representative, "Research in the Iron and Steel Industry," in National Research Council, Research--A National Resource, vol. II (Washington, D. C., National Research Council, 1940), p. 158.

[38]"The existing theory of the behavior of steel did not provide sufficiently detailed guidance for design and construction purposes. The need for such guidance in numerous specific industrial contexts provided a powerful impetus for the establishment of new testing facilities." See Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 30. See also Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 28; and Bartlett, "The Development of Industrial Research in the United States," p. 27-29.

[39]See National Research Council, Industrial Research Laboratories of the United States, various years, 1921-46.

the speed of the chemical reactions was so rapid that it was difficult to maintain quality control.[40]

However, consuming firms encountered much resistance from producing firms to their early research efforts. Steel producing firms were reluctant to accept and integrate the research of steel consuming firms, being skeptical about the use of industrial research to improve steel products and processes. They remained confident that rule-of-thumb methods were sufficient for steel production, an attitude exemplified by A. L. Colby of Bethlehem Steel when he complained about "the unjust and often absurd chemical requirements included in steel specifications compiled by overzealous engineers with little if any practical knowledge of steel metallurgy."[41]

So, whereas the industrial research practiced by steel consuming firms came to be directed at learning basic metallurgical phenomena and improving the quality of steel, such questions remained of little concern to most steel producing firms at the turn of the century.[42] What accounted for the disagreement between steel consuming firms and steel producing firms regarding the efficacy of industrial research into the quality of steel output? This question will be explored at length in the next two chapters.

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[40]Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 40; and Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 31.

[41]The Iron Age, January 15, 1902, p. 8.

[42]The development of a science of metallurgy or 'materials science' was a slow process, "by no means completed by the outbreak of the First World War." See Mowery and Rosenberg, Technology and the Pursuit of Economic Growth, p. 31.

CHAPTER 3

THE PENNSYLVANIA RAILROAD: A PROMINENT STEEL CONSUMING FIRM THAT PIONEERED IN INDUSTRIAL RESEARCH

Section 1. Introduction

Over the last three decades of the nineteenth century, Bessemer steel became an important industrial input in many new and existing products, all requiring steel of increasing reliability and strength. Prominent steel consuming firms and technical associations initiated scientific investigations in order to expand their scientific knowledge of plain carbon steel, knowledge that would eventually serve as a basis for improvement of steel quality and development of new steel products and processes. Many steel consuming firms established labs for the purposes of organizing systematic research into the desired characteristics of steel products used by their firms, and began to insist on obtaining better quality steel or different kinds of steel for their products.

Foremost among them was the Pennsylvania Railroad (the PRR). The Pennsylvania Railroad established its testing and chemical labs in 1875; and its industrial research into steel eventually sparked greater industrial research efforts on the part of many steel producing firms. The PRR was an influential member of the American Society for Testing Materials (ASTM), an organization founded in 1898 to bring together producing and consuming firms interested in the chemical and physical properties of a wide variety of commercial engineering materials (for more information on the ASTM, see Chapter 4 below).

Section 2. Brief History of the Pennsylvania Railroad

During the last three decades of the nineteenth century, the U.S. railroad industry was characterized by a high degree of horizontal consolidation and interfirm cooperation. Through these concurrent processes of consolidation and cooperation, a national railroad system composed of large firms possessing considerable market power and linked to each other through various cooperative railroad associations emerged.

The first attempts at consolidation took the form of the famous railroad pools of the 1870s and 1880s.[1] The pools--mere informal alliances--broke down when the volume of railroad traffic stopped increasing. Many railroads turned to formal horizontal consolidation to eliminate ruinous competition. Over the last two decades of the nineteenth century, the largest railroads created "giant systems,"[2] some of which controlled five to ten thousand miles of track.

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[1]Pools were a response to "ruinous competition" in the railroad industry during these decades. Before the pools, most railroads attempted to cover their high fixed costs by adding more cars to every train run, and then reducing rates and engaging in price wars in order to fill these extra cars by taking traffic away from rival roads. See Eliot Jones, "Is Competition in Industry Ruinous?," Quarterly Journal of Economics, XXXIV, May 1920, pp. 473-519; and Chandler, The Visible Hand, pp. 134-43.

[2]Chandler, The Visible Hand, p. 134.

During this time, middle managers for many railroads began to work together to standardize operating procedures, track, and equipment in order to integrate rail traffic on a national basis and to cooperate in solving related technical problems. Several technical and professional associations were established for railroad representatives to meet and discuss these common problems: the Society of American Civil Engineers, originally established before the Civil War, was resuscitated in 1867, and a number of new railroad associations came into existence, including the important American Railway Association. These technical and professional associations enabled rapid diffusion of innovations throughout the railroad industry, and encouraged the railroads to work together to improve railroad products:

> Professional exchanges encouraged improvements in locomotives, tracks, and other facilities, as well as standardization of couplers, air brakes, and signals, because these products were designed and improved by the railroad departments and not the manufacturers.[3]

The Pennsylvania Railroad (PRR) was one of the leading railroad systems in the U.S. during the late nineteenth century. In these decades, the PRR increased its total track from five hundred to six thousand miles (equivalent to eight percent of the nation's total rail mileage at the time), obtained access to major commercial centers and

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[3]Chandler, The Visible Hand, pp. 123-33. Other new associations included: the American Railway Master Mechanics Association; the American Society of Railroad Superintendents; the Master Car Builders' Association; the Roadmasters Association of America; the National Association of General Passenger and Ticket Agents; the National Railroad Agents Association; the American Ticket Brokers Association; the General Baggage Agents Association; and the Society of Railroad Comptrollers, Accountants, and Auditors.

important natural resources, and integrated vertically to many related industries.[4]

In building and managing its large horizontally- and vertically-integrated railroad system, the PRR pioneered many important aspects of railroad operation--most notably, the decentralized line-and-staff divisional form of organization, which permitted more efficient coordination of the railroad's activities and central planning. The PRR was widely recognized as being successful due to its organizational innovations.[5]

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[4]Chandler, The Visible Hand, pp. 151-154. In addition to horizontal consolidation, the PRR acquired partial or total control of firms in related transportation industries such as the American Steamship Company, the International Navigation Company, the Union Railroad and Transportation Company, and the Empire Transportation Company. As well, the PRR entered into upstream and downstream industries such as mining and manufacturing; two noteworthy ventures were its investments in the Pennsylvania Steel Works and the Pullman Palace Car Co. However, they decided to pull back from some of these peripheral activities--notably Pennsylvania Steel--in the depression of 1873.

[5]Chandler, The Visible Hand, pp. 156, 169. This form of organization was copied by many roads after the Civil War, when they began to carry heavier traffic over longer distances and to solve the organizational problems created by the increased traffic, increased freight-loads, and the increased number of lines controlled by one road, with a managerial hierarchy that could coordinate, not only the various lines of traffic, but all the varied business activities of the road. A British railroad expert in 1893 commented that "'The Pennsylvania is in every respect the standard railway of America. . . . Its rails and rolling stock, its ballast and bridges, its stations and service are regarded as embodying a state of perfection, to equal which should be the highest ambition of every railroad in the country'" (p. 176).

Section 3. Establishment of the PRR's Test and Chemical Departments

Industrial testing was one of many activities centralized by the PRR.[6] The PRR learned that it could not rely solely on producing firms' reputations to guarantee that it was purchasing materials of acceptable quality, as C. D. Young, head of the PRR test department in the early twentieth century, observed:

> Neither the reputation of the manufacturer nor a superficial inspection of the materials offered has been found to be a sufficient safeguard in the purchase of supplies, since frequently the manufacturer himself has no positive knowledge of the strength or other physical properties of the iron, steel or other metals, nor the purity of many of the articles offered for sale.[7]

The central test department, established at Altoona in 1874, and the affiliated central chemical laboratory, established at Altoona in 1875, were created in response to the railroad's need for reliable information concerning the quality of materials supplied to the railroad.

Centralization of testing activities led to six decades of industrial research into the properties of old and new materials alike:

> . . . careful consideration of the materials available for the various uses of the railway, . . . by research work tending toward the development of new materials and devices, or improving those which are in general use.[8]

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[6]Chandler, The Visible Hand, p. 178.

[7]C. D. Young, "The New Physical and Chemical Laboratory of the Pennsylvania Railroad Company," American Society for Testing Materials, Proceedings, Vol. XV, Part II, Technical Papers, p. 349: as Young stated, "an organization with laboratories at a central point is an essential in promoting the work of thorough inspection, the importance of which is unquestioned. With this inspection, accident to the travelling public and the employe [sic] have been reduced."

[8]Young, "The New Physical and Chemical Laboratory of the Pennsylvania Railroad Company," p. 349.

This was research aimed at developing a body of consistent scientific knowledge about the properties of existing products and processes used by the railroad, and was closely integrated with its ongoing day-to-day activities--moving the trains.

Before 1874, PRR engineers had conducted some tests of materials, but not always in systematic fashion. In 1873, all physical testing functions for the railroad were centralized under Theodore N. Ely, then PRR's Superintendent of Motive Power, at Altoona, Pennsylvania, the site of PRR machine shops. By 1874 the newly centralized testing functions were considered important enough to be organized into a separate department of physical tests and was given its own director, John W. Cloud, the first Engineer of Tests.[9]

The PRR was a major consuming firm interested in developing a reputation for reliable service, and toward that end, procuring reliable and quality products. Its two labs moved quickly to establish systematic physical and chemical testing of a variety of materials used by the railroad--coal, oils, paints and steel. The test department analyzed the physical characteristics of materials while the chemical department analyzed the chemical aspects. The two labs cooperated to establish the requisite characteristics for railroad products by creating specifications for existing materials and conducting research to discover useful new materials.

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[9]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, Pennsylvania Railroad Papers, Test Department Records, Accession 1810, Hagley Museum and Library, Wilmington, Delaware (hereafter, PRR File).

One area of research emphasized by the PRR test department was steel products.[10] In 1874 the PRR purchased its first testing machine--a metal testing machine with a gauge to determine the elongation or deflection of metals within one-hundredth of an inch; the first tests were made on stay bolt iron manufactured by the Altoona Iron Company. In 1876 the PRR purchased a second machine that used a moving pencil point to measure torsion and other physical properties of metal. Yet many "important tests were made by methods which did not require the use of a complicated machine."[11] In the "drop test" used to determine the soundness of steel car axles, a sample axle was balanced on two cast iron blocks and struck in the middle by a 1,640 pound-anvil; the resulting depression (or in severe cases, the extent of breakage) indicated whether or not the metal was acceptable.[12] A simple test was used to determine coal quality: two locomotives of "roughly equal" efficiency would be dispatched on the same route, carrying loads of equal size but fueled with two different types of coal in order to compare the relative efficiencies of the two coals.[13]

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[10]The steel products studied by the PRR included boiler and other forms of sheet steel, passenger axles, crank pins, iron brake chains, springs, and car wheels. See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[11]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[12]The lab also employed simple sampling techniques in their early testing of materials: for example, testing procedures for axles specified that one of every hundred axles be tested, and if it passed, all axles of the lot were accepted; if it failed, all were rejected. See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[13]At a designated point, the two coals would be switched so as to eliminate any difference in the locomotives' mechanisms. Testing engineers recorded the locomotives' respective consumption of coal and

By the early twentieth century the test and chemical departments had established themselves as integral parts of the corporation.[14] Specifications were devised for many PRR materials and all materials purchased according to specification were examined by the test department and chemical lab. The number of tests increased each year: between 1880 and 1910 the number of annual tests conducted by the test department alone increased from 5,700 to 85,500.[15] The PRR allocated more resources to the labs to accommodate the increased testing. For example, between 1874 and 1910, the number of employees increased to 210, a faster rate of increase than for the railroad overall:

> The growth of the test department and laboratory has been very much more rapid than the increase in tonnage hauled, or the extension of the general business of the railroad. The reason for this is that there was almost as wide a field for the application of specifications, and the inspection and testing of materials, in the beginning as at the present time.[16]

In 1913 the PRR constructed a new building for its test department and chemical laboratory. The design of the new building signalled steel

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water, the train weights, the steam pressure in the boilers, the weather, the condition of the track, the running time, the burning of the fire, and the quantity of ashes removed. See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[14]The labs, in the view of the railroad administration, solved the problems that arose "in the intercourse and dealings of a great corporation with the commercial world . . .—the equitable payment for what the corporation buys and the certainty of being able to buy material of the quality that the corporation needs." See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[15]"Summary of Annual Statements," Pennsylvania Railroad Test Department, n.d. (circa 1913), Box 661, PRR File.

[16]Young, "The New Physical and Chemical Laboratory of the Pennsylvania Railroad Company," p. 351.

producers that the PRR would be involved, to an even greater extent than in the past, in studying new manufacturing techniques and new products for the railroad's future use. The new building included both a separate heat-treatment lab and a small manufacturing laboratory where "new products are manufactured . . . until such time as it is found advisable to purchase them from 'outside' manufacturers."[17] The PRR thus equipped itself to develop new products and processes rather than relying on producers to do such research: as Young noted,

> With the facilities described and the excellent organization built upon the experience of over forty years, it is apparent that the Pennsylvania Railroad Co. is in a position to exercise the closest supervision over its purchases and supplies. At the same time it is capable of not only keeping abreast with the developments of materials of construction, methods of health preservation and safety of railway operation, but should, as it has attempted to do in the past, be in the lead in dealing with the many and diversified technical problems continually arising.[18]

To analyze such consequences of the PRR's industrial research, it is necessary to consider the early testing activities of the PRR in some detail. Archives of the PRR's chemical and test departments held at the Hagley Museum and Library at Delaware contain summaries of the chemical department's work prior to 1900 and detailed records of the test department's work after 1900. This discussion of the PRR's industrial research efforts will begin with a description of the early efforts of the chemical laboratory in promoting industrial research into

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[17]Young, "The New Physical and Chemical Laboratory of the Pennsylvania Railroad Company," pp. 362-365.

[18]Young, "The New Physical and Chemical Laboratory of the Pennsylvania Railroad Company," p. 375. The PRR's research into new alloy steels and new manufacturing processes will be discussed in more detail below.

steel, and will follow with a description of the later efforts of the test department.

Section 4. Early Activities of the PRR Chemical Department

The PRR established its chemical department in 1875 and hired Dr. Charles B. Dudley to head the department and to perform, in-house, the chemical investigations previously conducted by outside chemists. Charles Dudley was an academically-trained Ph.D. chemist and not a "rule-of-thumb" man.[15] As head of the lab, he moved the PRR into scientific investigations of the chemical properties of railroad materials.

One of Dudley's earliest studies for the PRR was an investigation of corrosion in steam cylinders. Through his analysis of lard oil--an important lubricant--it was found that the expensive lard oil usually purchased by the PRR was frequently contaminated by "reputable" manufacturers with cheap and "almost worthless" cottonseed oil, causing corrosion. Dudley then devised a method to detect the presence of cottonseed oil.[16] This early investigation established an important principle of PRR research--reliance on scientific analysis rather than price as an indicator of quality.

One early steel investigation was prompted by the PRR's desire to replace costly and flimsy india rubber springs with steel springs. A

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[15]Dudley was a graduate of Yale and the Sheffield Scientific School in England. See "File Guide to the Pennsylvania Railroad Papers," PRR File.

[16]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

series of experiments produced both suitable steel and a procedure for testing the steel; by 1885, the PRR was using so many steel springs in traffic that the chemical department was testing 81,000 steel car springs annually. Furthermore, as Dudley observed, the PRR's research efforts had elicited improved quality steel from spring producers:

> In the early days, the spring shop, with the manufacture, was a place where material could be used up that was not satisfactory for other and more expensive uses. To-day the spring manufacturer who makes springs for the Pennsylvania Railroad Company, makes a special steel for this purpose, and to the Railroad Company, this change in the kind of metal used, together with the redesigning of the springs by the Mechanical Engineer, has resulted in a diminution of breakage of spiral springs, from several tons a month to a rarity.[21]

A famous investigation by the PRR chemical department under Dudley was the steel rail study,[22] undertaken in 1879 to establish the relationship between the durability and hardness of steel rails. This study served as the starting point for the PRR's long-term industrial

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[21]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File. Other early investigations of the chemical department included locomotive boilers, lighting devices for passenger coaches, purification methods for the water used by locomotives, anthracite and bituminous coal, and crude oil.

[22]The PRR was one of the first railroads to begin using Bessemer steel rails. It imported 150 tons of steel rails from England, but did not place these rails in track until 1866; "as the rails appeared very brittle, it was not deemed expedient to place them in the main track where they were passed over by trains at high rates of speed. None of them, however, were broken in the track, and as they exhibited little or no appearance of wear, other steel rails were ordered in 1867, of a quality combining more toughness with a sufficient degree of hardness, and experiments were continued to test the relative merits of the several descriptions of rail." See Sellew, Steel Rails, p. 4.

research into steel rails.[13] Dudley took sixty-four rails from PRR tracks--sixteen each from level tangents, level curves, graded tangents, and graded curves--a sample that included the most slowly- and the most rapidly-wearing rails. Dudley concluded that rails made of softer steel were less liable to crush or break in service and gave twice the service of harder steel rails. Therefore, the railroad could obtain considerable savings by asking for softer steel in its rails, and Dudley prepared the first PRR specification for steel rails which stated the precise chemical composition needed for softer rails[14] and mandated the use of a simple bending test to verify that the steel had the desired physical characteristics.[15] This specification was issued by the PRR to steel rail producing firms, who were expected to alter their techniques to comply with this specification.

Another early steel specification from the chemical lab's testing was for boiler and firebox steel. Because this specification took years to develop, it illustrates both the complex investigation undertaken by

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[13] "Research work for the improvement of rails was begun, and the investigation and accumulation of experience, which later made possible the preparation of a series of 'Standard Specifications,' had their start." See Young, "The New Physical and Chemical Laboratory of the Pennsylvania Railroad Company," p. 350.

[14] The specifications required: "Phosphorus, not to be above 0.10 %; Silicon, not to be above 0.04 %; Carbon, to be between 0.25 % and 0.35 %, 0.30 % as the ideal; Manganese, to be between 0.30 % and 0.40 %, with 0.35 % as the ideal; no specifications for sulphur or copper content." See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[15] "Test pieces would be cut from the web of the rail 12 inches long, 1 1/2 inches wide, 1/2 inches thick and should be able to stand a maximum load not exceeding 3,000 pounds, bending "not less than 130 degrees without rupture." See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

the lab and the lack of concrete knowledge about steel in these early days. The specification

> . . . was not drawn up till after years of study [sic] of steel taken from locomotives which had been in service, and all of the data carefully studied. It was found that a certain amount of carbon was desirable for obtaining a certain strength and durability of stay bolt threads, and a sufficient degree of hardness to resist abrasion, mechanical injury in introducing new flues, etc., but that if this was allowed to run too high, difficulty such as cracking was encountered in shaping, making necessary flanges, etc. It was found that the desired tensile strength could be obtained with carbon with less detriment to elongation, elasticity and working properties, than by the use of other elements, including manganese. High sulphur and phosphorus was found to be objectionable.[16]

But the careful work paid off: the specification issued in 1892 remained in similar form until at least 1913, in spite of a number of technological changes to locomotive engines.[17]

In fact, in most cases, the results of PRR testing were codified in specifications. Dudley used the specification-making process as a systematic way of collecting knowledge:

> At first the work consisted largely in investigating difficulties and suggesting remedies. As information was accumulated from time to time on any single subject, this information was gradually collected together and arranged, and out of it came a statement as to what qualities the material used in any place, should possess. A description of these qualities, and the tests necessary to secure them, was put in print and was called a 'specification' for that material.[18]

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[16]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[17]The specification thus ". . . served as a model for many consumers, and the changes which have been made up to the present time are, comparatively speaking, insignificant." See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[18]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

Dudley stressed five practices in specification-making and specification-using that guided the operations of both the chemical lab and test department. The systematic, scientific approach developed by Dudley guaranteed that useful tests would be developed for determining the reliability of materials and that the knowledge thus accumulated would be compiled into a usable body of information that could be shared with others.

First, the labs used varied testing techniques and repeated experimentation, using techniques and information from other experts when possible:

> It, therefore, becomes necessary to try a number of suggested things for each object or purpose. This practical trial shows that certain parts fail, while others may be found to be usable, and still others show a very marked superiority. . . . This procedure is necessary in achieving the highest results along any line of railroad supplies.[29]

Second, the PRR verified all outside information itself and conducted all necessary tests in its own labs; as Dudley argued:

> . . . this railroad has always believed in having first hand information on the material used and not depending on information furnished by independent interests which may be influenced in their judgment by perhaps unintentional mercenary motives.[30]

Third, the results of PRR tests were incorporated into specifications that identified the requirements for quality materials. Ideally, specifications contained detailed lists of the required physical and chemical characteristics, the required tests to guarantee the

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[29] "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[30] "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

presence of these physical and chemical characteristics in the purchased material, and the required sampling procedures, so as to leave no room for doubt on the part of the manufacturer about what was expected in the finished product: "When a method is specified the manufacturer is better able to turn out a definite composition."[31]

Fourth, specifications were always drawn up through a process of consulting with producers. This was an important contribution of the PRR to research into steel between 1870 and 1930, and will be dealt with at length in section 5.

Finally, materials were returned to the producer if they did not meet specifications:

> . . . of [sic] the composition comes within the limits designated the shipment is accepted. If, however, the chemical results do not come within the specification limitations the shipment is marked rejected and the material which the sample represents is returned to the manufacturer from whom it was obtained.[32]

The careful research and systematic practices of making specifications made them quite effective:[33] as of 1913, few changes in

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[31]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[32]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[33]A study of soap used to clean PRR train cars produced one spectacular albeit unexpected success for the labs: "after a passenger coach on the Pennsylvania Railroad had been through the hands of the car cleaners, it was noticed by some of the officers that the paint on the outside looked very badly . . . As a matter of discipline, the car cleaners were called to account, and requested to explain why the paint and varnish had been so badly injured. Their reply was that with the soap that was furnished for car cleaning no better results could be obtained. . . . to give the men the benefit of the doubt, a sample of soap was obtained and submitted to analysis, when it was found that this soap actually contained over three per cent. of free caustic soda and about seven per cent. of sodium carbonate. It is evident that this

many of the original chemical compositions for materials contained in PRR specifications had been deemed necessary.[34]

Specifications were developed for a wide variety of materials. By 1913, the chemical lab had devised fifty-six specifications that listed chemical requirements for materials, twenty-three of these pertaining to important steel products:[35]

> The specifications so far have pertained principally to steel products. They have been considered first not only on account of their commercial importance, but also from the

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soap had been very carelessly made from cheap materials . . . . the circumstances above described led to the preparation of a specification for common soap, in which the amount of free and carbonated alkali was limited to very low figures, and that no similar difficulty of destruction of paint and varnish has since been observed." See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[34]Two examples indicate the substantial reductions achieved in the rate of failed materials by using specifications. There were no important changes in the original chemical composition for helical steel springs during these decades, and the improved chemistry of the steel in these springs was credited with helping to reduce the rate of failures in helical springs: "before any chemical specification was issued for helical springs, the number of breakages was very high and it required only a few months to obtain a car load of broken spring scrap. After the specification had been in effect three to four years when about two or three hundred thousand of them were in service only twelve broken ones were discovered in three months." Similarly, no changes were made in the recommended chemical composition for driving axles: "before the present specification for car and driving axles were issued many breakages resulted, most of them being detail fractures. Large numbers of these were sent to the Laboratory for tests, and it was almost invariably found that the carbon content was low, usually running from .22 to .26 per cent. Since the present specification has been enforced, very few breakages have occurred." See "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR file.

[35]As well, the chemical department developed specifications for paint, petroleum, lard oil, tallow, soap, rubber insulated wire, blur vitriol, sulphuric acid, soap and detergent, caustic soda, sal ammoniac, wood creosote, turpentine, soda ash, plush, torpedo product, fuses, passenger car thermometer, cement, battery zinc, asphaltum pitch and disinfectant.

> fact that the use of inferior steel might endanger the lives of passengers and employee.[36]

PRR specifications that contained requirements for both chemical and physical properties covered more than one hundred materials. These specifications were continuously reviewed and modified when necessary. The PRR specifications were regarded as the standard specifications for some materials, notably steel rails.[37] In short, the two departments were quite successful in improving materials and reducing costs:

> While the small percentage of material rejected . . . speaks well for the beneficial influence exerted by the Test Department upon the manufacturers whose products were inspected, the fact that the value of the supplies rejected has amounted to a very large sum each year, is sufficient evidence of the practical and financial value of the department of tests in its relation to the purchase of supplies and materials irrespective of the additional assistance rendered it in all questions relating to locomotives and to the many appliances belonging to motive power, car and other equipment.[38]

Section 5. Making and Using Specifications at the PRR

a. General Information

In 1915, Henry Gulick, owner of an independent testing firm, acclaimed the PRR's willingness to share technical information with all

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[36] "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

[37] See, for example, "New Pennsylvania Railroad Specifications for Rails" (editorial), The Iron Age, February 13, 1908; and Section 5 of this chapter.

[38] "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

interested persons or agencies.[39] Through the PRR's systematic testing, specification-making and using, and special investigations between 1870 and 1930, the PRR shared research results with other railroads and technical associations in an effort to improve various steel products, and helped to establish a foundation of scientific knowledge about steel. Moreover, the PRR's practice of consulting with producers in making specifications was an important means of diffusing technical information throughout the steel industry. The PRR's industrial research was directed at incremental, cumulative improvements in materials and was largely carried out in cooperative manner with suppliers. The PRR's interactive process of research will be described first in general terms, and then in the context of some specific examples.

The PRR established its procedure of consulting with materials suppliers when making its first specifications in the 1870s. The purpose was to determine whether the technical details in their specifications could be met by producing firms. Specification-making was a slow, cumulative process of product improvement:

> The making of specifications was necessarily slow and laborious. Owing to the demands of the service, many points of excellence had to be assured, and the accumulation of information covering these various points not infrequently occupied two or three years.[40]

Making and using specifications was systematized into an interactive and iterative process of "learning by using" from the

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[39]Henry Gulick to C. D. Young, July 27, 1915, Box 665, PRR File.

[40]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

beginning. Painstaking research and compilation of findings was first carried out to determine the desired properties of materials. When sufficient information was deemed to be available, it was codified in the form of a proposed specification. This proposed specification was sent to producing firms for their comments before being formally issued. By means of this process, the PRR gained the acceptance, and in some cases, the cooperation, of many producing firms. Moreover, the cooperative process of making specifications with suppliers was an important way in which the PRR induced industrial research on the part of some producing firms.

Specifications, once issued in final form, served as the basis of contracts with producing firms; in effect the PRR used specifications to inform suppliers that it would purchase products only from those producing firms who could meet its specifications. The PRR induced industrial research on the part of some producing firms when many of those firms that wished to do business with the PRR established their own testing procedures to meet the contractual obligations implicit in PRR specifications. All PRR specifications contained a clause that material found not to conform to the road's specifications would be returned to the manufacturer, at the manufacturer's expense, to be replaced with the proper material:

> Notwithstanding these precautions new manufacturers, especially those who had little experience in working according to specifications, very frequently failed. Also it is well known that commercial processes in the making of materials are more or less uncertain, and do not always yield the product which is desired. Owing to these two causes, to which might be added an occasional attempt at genuine falsification, which attempts were few, it not infrequently happens that materials did not fill the requirements. In these cases the universal rule of the

> Railroad Company was to return the materials to the shipper, with request to have them replaced with material according to specifications.[41]

Producing firms began to move slowly into industrial research. Early on, materials suppliers labored simply to meet PRR specifications; later, they worked to improve products. In the case of steel, the PRR's interactive process fostered development of a body of knowledge about steel as well as the later exploitation of that knowledge--a multidirectional process of innovation that relied on considerable interaction between suppliers and users who were "learning by using."

The discussion that follows recounts information found in the PRR archives on its process of making and using specifications to standardize, and later, to improve, steel products. Specification-making and using for a variety of steel products will be considered, and specification-making and using for steel rails will be discussed in some detail. These examples will give this general description more precision and clarity.

b. Making and Using Specifications for Various Steel Products

Despite its early systematic efforts to develop reliable and scientific specifications, most early PRR specifications for steel products were neither scientific nor precise with regard to the desired chemical and physical properties in steel. At the time, there was a lack of consensus among both producers and consumers regarding the ideal

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[41] "Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

metallurgical qualities for many steels. The PRR could only request that materials have certain obvious performance characteristics in its early specifications. For example, the 1893 PRR specifications for billet or bloom steel simply stated that billets or blooms which failed to successfully make forgings would be returned to the manufacturer, but gave neither technical guidance nor detailed performance standards to producers. Similar lack of guidance was contained in its 1897 specifications for crank pin steel and its 1903 specifications for carbon steel driving axles.[42]

Early specifications for steel rails took one additional technical step by specifying physical tests--albeit, the simple drop test--to determine if the material met physical requirements. The chemical composition for rails retained as its basis Dudley's 1879 steel rail study and was not changed for three decades.[43] These early rail specifications provided little new information on the scientific basis of sound steel.

Nonetheless, these early specifications established the fact that the PRR would not accept defective steel, even if it could not yet establish the underlying metallurgical causes for such defects. A 1906 incident illustrates this. The PRR rejected a lot of one hundred car wheels manufactured by the New York Car Wheel Company on the basis

[42]Pennsylvania Railroad Specifications No. 4-A, for Billet or Bloom Steel for Forgings, August 15, 1893; Pennsylvania Railroad Specifications No. 6, for Crank Pin Steel, November 8, 1897; and Pennsylvania Railroad Specifications No. 5-A, for Carbon Steel Driving Axles, October 21, 1903; Box 659, PRR File.

[43]Recall that Dudley formulated this specification to obtain "soft" rail steel. See Sellew, Steel Rails, p. 328.

of a rather picturesque defect: "the mottling of the white iron into the grey iron in the tread was not sufficient."[44] New York Car Wheel lodged the following complaint, indicating the current paucity of scientific metallurgical knowledge and the tendency for many producing firms to rely on rule-of-thumb methods:

> . . . if it was the desire of your company to have a deeper mottling between the white and the grey iron that was a very easy thing to accomplish . . . . Speaking from the standpoint of a good many years experience in the practical manufacture of wheels, the making of mixture and the cupola practice for the same, that the mottling of the grey iron may be an indication of good material but it is no proof of that fact.[45]

The PRR established systematic scientific activities in its test department and chemical lab, so as to meet its own requirements to test all materials in-house. As a result, rigorous testing of existing materials was the dominant activity in the early days of the labs:

> The specification states how the sample shall be taken in all cases. . . . When the samples are received at the Laboratory, they are properly registered as a matter of record. The samples requiring special preparation, such as drilling steels and alloys are then taken in hand by Laboratory assistants whose entire duty it is to perform such work, the method of taking drillings being given in the specifications. All samples are eventually turned over to the analysts in the chemical laboratory, each analyst being a specialist on certain determinations. The methods of analysis are part of the specifications, all purchases being based on our methods as part of the specifications. These methods are given to all manufacturers who care for them.[46]

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[44]P. H. Griffin to E. D. Nelson, October 15, 1906, Box 690, PRR File.

[45]P. H. Griffin to E. D. Nelson, October 15, 1906, Box 690, PRR File.

[46]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR File.

If defects were found, a second sample was tested; if the second sample failed, the entire lot of material would be rejected and shipment prevented. Rejected samples were held at the testing laboratory for one month, during which time the manufacturer could appeal for retesting. The Brinell test to test the hardness of steel was applied to certain steel materials--rails, wheel and spring materials, castings and alloys.[47] All in-house analyses had to be completed before material could be shipped; and the PRR was adamant regarding this standard provision in their specifications.

The testing workload in the PRR labs became quite heavy, causing frequent delays in shipments by producing firms who were waiting for test results. Several steel-producing firms who had initiated, or wished to initiate, their own testing attempted to avoid these delays by trying to persuade the PRR to permit them to perform tests in their own labs. In 1912, both Illinois Steel and Standard Steel requested permission to perform tests at their own labs because the PRR facilities were so far distant. The PRR agreed to station a PRR employee nearby to expedite the tests, but declined to shift responsibility for testing to suppliers. Worth Brothers, a manufacturer of boiler plate, established its own testing facilities in the early 1910s and subsequently offered to perform the requisite tests on boiler plate supplied to the PRR. The PRR acknowledged that the new test facilities of Worth Brothers were good,

[47]"DESCRIPTION of METJODS [sic] of TEST made in accordance with the requirements of P.R.R. SPECIFICATION No.36-A covering STEEL CASTINGS [sic];" "DESCRIPTION of METHODS of TEST made in accordance with the requirements of P.R.R. SPECIFICATION No.59-B covering ROLLED STEEL FOR USE IN THE CONSTRUCTION OF METAL PASSENGER CARS [sic];" "BRINELL TEST for HARDNESS of DIFFERENT METALS [sic];" Box 661, PRR File.

but restated that chemical analysis of all materials would continue to be done at Altoona.[48]

The problem of delays in testing was exacerbated as more steel producing firms established their own labs and wanted to perform their own tests. In 1915 Buckeye Steel Castings complained about congestion in their mills due to test delays, but were notified that if samples were handled promptly by Buckeye, the PRR would endeavor to get test results to Buckeye within twenty-four hours.[49] In 1920 S. Severance Manufacturing proposed to install a tensile testing machine and a chemical laboratory to be able to perform required tests in order to end the "handicap of insufficient storage room while waiting for test results."[50] Severance too was advised that "we desire to adhere strictly to the requirements of the specifications."[51] In 1922 Bethlehem Steel lodged a similar complaint:

> . . . our works, laboratories, and testing facilities are sufficiently large and well-established, and . . . [as] these laboratories check closely with your laboratories, it would seem that in our case you would be fully protected by accepting material on the results obtained by our testing and laboratory force.[52]

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[48]H. M. Ramsay to C. D. Young, April 12, 1912; S. Porcher to J. T. Wallis, n. d. (circa 1912); H. M. Ramsay to C. D. Young, April 23, 1913; and C. D. Young to J. L. Hughes, April 30, 1913; Box 658, PRR File. The PRR did offer to re-check Worth's test pieces in their own laboratories as a check on the accuracy of the Worth Brothers' testing machines and procedures.

[49]Engineer of Tests to S. H. Summers, December 6, 1915, Box 658, PRR File.

[50]T. S. Reynuleb to F. M. Waring, March 20, 1920, Box 658, PRR File.

[51]Engineer of Tests to S. Severance Manufacturing Company, March 31, 1920, Box 658, PRR File.

[52]F. A. Weymouth to F. M. Waring, March 28, 1922, Box 658, PRR File.

Yet the PRR was

> not yet prepared to go to this method of inspection at the mills, and in any case, we would not care to make a change which would affect one company only but would endeavor to work out a system that would apply to all manufacturers at the same time.[53]

The PRR insisted on performing their own tests because they believed that their in-house testing procedures were superior to those of steel producing firms. Manufacturers often used different testing techniques or tested the metal at different stages in the manufacturing process, with the result that producers' test results were often inconsistent. Moreover, the PRR believed that producing firms were less careful in testing.[54] To confirm their suspicions, the PRR commissioned a study in 1914 by the independent testing company, R. W. Hunt & Company, in which Hunt's testing procedures were compared to those of several manufacturers of steel rails. R. W. Hunt determined that many sample lots of rails that passed manufacturers' tests would have been rejected by more rigorous testing.[55] Enforcement of the PRR's

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[53]F. M. Waring to F. A. Weymouth, March 31, 1922, Box 658, PRR File.

[54]In one case, the PRR compared the analyses of the Forged Steel Wheel Company to their own, in the context of a cooperative steel wheel investigation between the two firms. The PRR found differences in thirty-seven percent of the analyses, and noted that "some condition in your laboratory should be taken care of which would permit analysis of steel showing .58 carbon, whereas the actual carbon on check analysis is 82 . . . . After you have gone over this matter with your laboratory, I would be pleased to hear further from you in reference to the difference which apparently exists between your work and ours." See Engineer of Tests to C. G. Bacon, September 16, 1912, Box 688, PRR File.

[55]The PRR test department concluded that "the time has arrived when the purchaser of rails needs a closer supervision over the mill analysis than is at present the case and I believe our specifications will amply take care of this feature." See Engineer of Tests to J. T. Wallis, March 3, 1914, Box 664, PRR File.

requirement for in-house testing was viewed as the only reliable way to get reliable steel.

Despite these conflicts over delays and test results with producing firms, the PRR's work with steel manufacturers did not always take an adversarial tack. The PRR had, early on, instituted a practice of working with manufacturers to develop specifications. The PRR's efforts to develop a new specification for steel wheels during 1911 and 1912 show its typical process of working with steel producers to develop specifications:

> . . . the main purpose of this investigation is to develop a physical test for the rolled steel wheel specifications and obtain other important information that obviously will be brought to light during the progress of these tests. We, of course, will be perfectly willing to give you information as to the results of our tests on any of your material submitted, but this information will be held strictly confidential and will not be given out to other wheel manufacturers or competitors. It has also been deemed wise not to have the various manufacturers come to Altoona to witness the test on their own products.[56]

The PRR requested sample wheels from cooperating producers. In 1911 the PRR approached Midvale to request experimental steel wheels.[57]

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[56]Engineer of Tests to Midvale Steel Company, March 11, 1912, Box 688, PRR File.

[57]Midvale would supply two ingots from separate heats and the mill's analysis of the metal; and wheels manufactured accordingly: five wheels made according to the present method and from the existing specification for steel, five wheels made according to the present method but keeping the carbon content of the steel between 0.40 and 0.50 percent, five wheels made according to the specifications for rim cooling, five wheels made according to the specifications for cooling of hub, five wheels annealed in the soaking bed, five wheels to be heat-treated, five wheels to be made according to Midvale's best steel and then to be heat-treated, five wheels to be made according to fish-scale stacking, and five wheels to be cooled in an annealing pit. See minutes of conference with Midvale Steel Company representatives Furness and Aertsen, November 14, 1911; and Engineer of Tests to Midvale Steel

Midvale requested additional information, relaying their "anxiety to co-operate with you in your investigation, so far as we consistently can, and [hoping] that you will see no impropriety in our desire to be further informed on certain points as a preliminary."[58] Midvale was especially concerned about some of the proposed treatments for the experimental wheels as they "would represent poor practice and would never be applied in regular manufacture."[59] The PRR also solicited cooperation from Forged Steel Wheel and Carnegie Steel, but had to persuade Forged Steel to participate because Forged Steel was leery of the experimental work proposed by the PRR:

> . . . All our study and investigative work has been along the line of devising and developing tests to determine the fitness of material for the service for which it is intended, i.e., an effort to read service results back into manufacture, and to arrange for due checks accordingly,--and our standards and methods are so arranged. Your experimentation seems to be along a different line, for instead of using Wheels made according to regular and approved practice, you have secured Wheels prepared according to unusual and destructive methods which, in my opinion, will render results of questionable value.
>
> Our methods, tests, etc., would not, therefore, be applicable in your case.[60]

Carnegie requested assistance on techniques for cooling the wheel rims and hubs and heat-treatment, and agreed to furnish the wheels "at

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Company, January 24, 1912; Box 688, PRR File.

[58]A. M. Sleine to C. D. Young, February 21, 1912, Box 688, PRR File.

[59]A. M. Sleine to C. D. Young, February 21, 1912, Box 688, PRR File.

[60]C. G. Bacon to C. D. Young, June 1, 1912, Box 688, PRR File.

a nominal price very close to the actual cost of manufacture."[61] Carnegie also agreed to permit the PRR's inspector to

> be present during the manufacture of the wheels and the ingot and split round, so that he can see that the manufacture takes place in accordance with your ideas.[62]

Despite the objective of developing "more scientific and advanced methods of tests . . . in connection with Solid Wrought Steel Wheels,"[63] the PRR lab relied on simple physical tests to determine the soundness of the experimental steel wheels: the sounding test and the drop test. The sounding test involved striking the wheel with a twenty-pound weight "in such a manner as to cause the wheel to emit a clear tone. This tone was caught on a special pitch pipe and classified."[64] The sounding test was eliminated from the final specification when it was determined that the tone emitted by defective wheels was as clear as that of flawless wheels. The drop test remained the best test available to test the finished wheels and only slight variations were made in the weights of the anvil, the points of contact, and the heights of the drops. But the drop test was still unsatisfactory: the specification that emerged from these experiments stated that steel wheels should be able to withstand a 1640-lb. anvil falling from a ten-foot drop--"no hardship

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[61]C. F. W. Rys to C. D. Young, March 12, 1912, Box 688, PRR File.

[62]C. F. W. Rys to C. D. Young, March 12, 1912, Box 688, PRR File.

[63]C. G. Bacon to C. D. Young, June 1, 1912, Box 688, PRR File.

[64]"Report of Steel Wheel Test," PRR Test Department, September 24, 1914, Box 688, PRR File.

on sound material . . . [yet] the necessity for such a requirement, however, is not at all clear."[65]

In the first two decades of the twentieth century there remained much confusion about chemical specifications because early chemical specifications had not succeeded in yielding uniform quality steel products; in fact, some defective material passed specifications. Material that met specifications and yet failed in service was frequently caused by use of the wrong kind of steel. One example was a 1905 failure in a steel car axle that caused a train wreck. The axle was taken to the PRR laboratories for chemical analysis where segregation and low tensile strength were found; yet the axle steel met current PRR specifications. A second axle, also conforming to PRR specifications, failed in 1906.[66] Such incidents indicated the need to begin to experiment with different kinds of steel:

> We cannot help thinking that the break emphasizes the importance of a change in our present specifications. Steel according to these specifications is too soft for our present figured strains, and there is really no indication of anything, so far as this case goes, except that the wrong kind of steel is being used.[67]

Frequently, materials that met specifications failed, due not to lack of research into better materials but to delay in integrating research findings into specifications because of economic considerations. One example was a proposed change to the specification for axle and boiler

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[65]"Report of Steel Wheel Test," PRR Test Department, September 24, 1914, Box 688, PRR File.

[66]C. B. Dudley to A. W. Gibbs, August 16, 1905; W. L. Brown to E. D. Nelson, November 3, 1905; C. B. Dudley to A. W. Gibbs, February 20, 1907; Box 691, PRR File.

[67]C. B. Dudley to A. W. Gibbs, June 21, 1905, Box 691, PRR File.

plate steel. Young observed that steel producers would increase the price of steel made under the proposed specifications and that

> . . . there is a question in my mind whether this increase in price would be warranted in the improvement which would be obtained in the steel. . . . it is very rare to reject on high sulphur, and, therefore, if an excessive amount of money were charged for the inclusion of this requirement in the specification, the expense might not be warranted.[61]

Economic considerations were important when the PRR considered changes to established specifications, with producing firm input given due consideration by the PRR. For example, in 1914, Pennsylvania Steel suggested a change in the PRR specifications for cast steel; however, the PRR chemical laboratory decided against the change for both technical and pecuniary reasons: they feared that the proposed change would increase the carbon content too much and they recognized that they could purchase economically priced cast steel within their existing specifications. Similarly, the PRR temporarily relaxed some specifications during World War I due to the labor and materials shortage that increased the price of materials purchased under specifications.[62]

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[61]Engineer of Tests to J. T. Wallis, n. d. (circa 1912-15), Box 664, PRR file. The proposed change was a limitation on the amount of sulphur in the steel.

[62]Regarding Pennsylvania Steel, see Engineer of Tests to F. D. Carney, March 3, 1914, Box 668, PRR File. Regarding the changes during the war, during which the PRR granted suppliers an allowance of five percent over the maximum limits, and after which the prewar limits were reinstated, see correspondence to American Steel Foundries, Union Steel Casting, Duquesne Steel Foundry, Birdsboro Steel Foundry & Machine Company, Atlantic Steel Castings, Fort Pitt Steel Castings, McConway & Torley, National Malleable Castings Company, Bethlehem Steel, Lebanon Steel, Pennsylvania Seaboard Steel, Egan Rogers, and Milton Manufacturing, November 12, 1920, Box 658, PRR File.

c. Making and Using Steel Rail Specifications

The increasing interaction with producing firms, and the gradual improvement in the quality of steel, are more clearly illustrated with the steel rail specifications, because more complete information regarding the PRR's research into steel rails is available in the PRR archives and in other sources--Iron Age and the Proceedings of the American Railway Engineering and Maintenance of Way Association.

The PRR was one of the few railroads engaged in research into rail steel in the early twentieth century.[10] In 1900, testing of steel was not widespread in either the railroad or the steel industry. As well, there was no universal agreement on the use of chemical and physical specifications. In fact, some railroads (and steel producers) thought specifications provided no guarantee of good rails.[11] Some railroads argued that universal specifications for rails were simply not

[10]Only one other railroad reported the establishment of a testing facility before 1900; two others established their labs in the decade following 1900. See National Research Council, Industrial Research Laboratories of the United States (Washington, D. C.: National Research Council, 1921. However, a 1911 PRR in-house survey examined the laboratory facilities of other railroads. Comments from these surveys indicate that there was considerable industrial research ongoing at many railroads at the beginning of the second decade of the twentieth century, although the PRR had the largest and most sophisticated lab. See J. D. Meyer to C. D. Young, November 16, 1911; H. B. MacFarland to C. D. Young, November 14, 1911; James H. Gibboney to C. D. Young, November 9, 1911; and "Railroad Chemists and Engineers of Tests;" all Box 714, PRR File.

[11]The main argument against specifications was based on an early study of a group of very old steel rails that had been produced by the John Brown Company in England in the 1870s. These had proven to be quite durable in service; when removed from track and analyzed, they were found to be, according to most current specifications, "chemically a 'poor lot.'" See American Railway Engineering and Maintenance of Way Association (AREMWA), Proceedings, Volume 13, p. 857.

useful because of the diversity of climates, ores, manufacturing processes, and traffic patterns in the U.S.[72] Some railroads relied on the chemical specifications of steel producing firms because they viewed chemical properties as being "only a minor part of the specifications of rail steel, compared with the physical requirements,"[73] or because they did not have their own laboratory facilities. Finally, some railroads used the PRR specifications.[74]

The PRR, by contrast, from early on, viewed specifications as indispensable. Beginning with Dudley's first specification for steel rails issued in 1879, the PRR initiated a long-term multidirectional process of industrial research into steel rails. The PRR pioneered in devising physical and chemical specifications for steel rail and in experimenting with new rail technology; its specifications for steel rails were of interest to other steel rail consumers and railroads and changes to these specifications were usually publicized in the steel industry trade journal, Iron Age.[75] The PRR frequently modified its specifications

> in the light of additional experience, [with] . . . the improvements which have been brought from time to time through the experiences and researches of its own committee and the committees of the other associations.[76]

By 1907 the PRR believed that its efforts to perfect steel rails had yielded better quality rails: as PRR engineer A. C. Shand observed, "the

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[72] The Iron Age, July 25, 1907, p. 24.

[73] AREMWA, Proceedings, Volume 13, p. 856.

[74] AREMWA, Proceedings, Volume 3, p. 209.

[75] See, for example, "New Pennsylvania Railroad Specifications for Rails" (editorial), The Iron Age, February 13, 1908.

[76] AREMWA, Proceedings, Volume 13, p. 861.

number of rails which have actually been broken in the main line running tracks of the Pennsylvania railroad is so insignificant as hardly to deserve mention." As well, the PRR had succeeded in obtaining "the best rails it can get for the money."[17]

Yet the PRR's early steel rail specifications seemed as unscientific as some of its other steel specifications. Pre-1900 specifications for rail steel specified that "the rail at the last pass should be at a red heat, preferably a dull red."[18] In 1902, the PRR announced new steel rail specifications but made only one change in the chemical composition--recommending higher carbon steel based on the results of experimental drop tests on high carbon steel rails, and one change in the physical tests--the new specification stated that the test piece should come from a designated location in the ingot, so that all rails from the heat would be at least equal in quality to the test piece.[19]

The PRR specifications were revised again in 1908. Iron Age noted that the PRR made these revisions in consultation with representatives of two important steel producing firms, and that the revisions were also based on "an exhaustive examination of the entire art and practice of rail manufacture."[20] Yet the primary change was not recognized as a great improvement: the only available physical test, the somewhat inadequate drop test, was made more stringent:

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[17]The Iron Age, July 11, 1907, p. 101.

[18]AREMWA, Proceedings, Volume 13, p. 858.

[19]AREMWA, Proceedings, Volume 3, p. 202.

[20]"New Pennsylvania Railroad Specifications for Rails" (editorial), The Iron Age, February 13, 1908.

> . . . as the heavy traffic has necessitated harder steel with higher carbon, to get better wear we are in the position to-day, with our stiffer sections and harder steel, where the drop test is causing the rejection of the very kind of stéel we need in track. In a recent series of tests made on pieces cut from the same rail, some of which were subjected to 15-ft. fall and some to 19-ft. fall, in almost every case where a rail stood the 15-ft. fall but broke under the 19-ft. fall the steel showed plainly by its fracture that it was not brittle, but simply hard steel which could not extend as fast as it is necessary for the extension flange to extend to avoid fracture.
>
> . . . . Some impact test is necessary to detect this condition, but it should be a reasonable test, one which differentiates between a strong, hard steel and a brittle softer one.[11]

Sampling was also made more rigid: rails from each blow of Bessemer steel would be tested; if one rail failed, the entire blow would be rejected. More systematic record-keeping would be implemented, with an "elaborate and comprehensive" marking system designed to keep track of rails according to manufacturer and location on the ingot, and a special PRR committee established to analyze this information and "to keep continually in thorough touch with the art"[12] of steel rail manufacture throughout the rest of the industry.

But in these 1908 specifications no attempt was made to determine with any precision the physical characteristics and chemical constituents needed for sound rail steel:

> . . . rails shall be free from 'injurious' mechanical defects and flaws. This differs from the old specifications in that no attempt has been made to describe the particular defects or flaws that will cause the rejection of rails. . . . no rails

[11]E. F. Kenney, "The Latest Results with Steel Rails," The Iron Age, July 2, 1908, p. 43.

[12]"New Pennsylvania Railroad Specifications for Rails" (editorial), The Iron Age, February 13, 1908; and E. F. Kenney, "The Latest Results with Steel Rails," The Iron Age, July 2, 1908, p. 43.

will be accepted that contain defects or flaws which in any way impair their strength.[13]

Thus the crucial aspects of improving quality--the manufacturing details that could make better steel--were left to the manufacturer:

> Most important of the features of the new specifications is placing more upon the manufacturer the responsibility for the character of the rail produced. The company recognizes that it is merely a purchaser, not a manufacturer. Considerable latitude is, therefore, to be allowed in the methods of manufacture utilized, so long as the result is a sound rail.[14]

Steel producing firms must have grumbled about the lack of clear guidelines in the 1908 specifications because, later that year, the PRR issued a statement that it had no conflict with one of its major rail suppliers, U. S. Steel, over the new specifications.[15]

In the 1910s, the PRR began to correct some of the imprecisions. By 1912, more precise chemical specifications--lower and upper limits on the carbon content of the steel, were issued, based on recent PRR research, with chemical tests to be conducted on-site by the manufacturer.[16] By 1915 more rigorous physical tests were added, to be conducted by PRR inspectors prior to shipment of the materials. New physical tests--tests to destruction and tests for elongation--would

[13]"New Pennsylvania Railroad Specifications for Rails" (editorial), The Iron Age, February 13, 1908.

[14]"New Pennsylvania Railroad Specification for Rails" (editorial), The Iron Age, February 13, 1908.

[15]The Iron Age, March 19, 1908, p. 918.

[16]The on-site tests involved the steel producers making, and reporting, two analyses on each ladle test ingot of Bessemer steel during every twenty-four hour production period, or on each melt of open-hearth steel.

supplement the drop test. A new stricture was added: PRR inspectors were to have free entry to the manufacturers' mill

> . . . at all times while the contract is being executed, and shall have all reasonable facilities afforded them by the manufacturers to satisfy them that the rails have been made and loaded in accordance with the terms of the specifications.[illegible]

Significantly, the new specifications required several manufacturing details as well: shrinkage limitations, cooling and storage procedures, procedures for hot straightening of steel, procedures for finishing the rails, and discard procedures. Although these additional chemical and physical tests at the manufacturers' sites increased rail prices, they were considered worthwhile because they provided a more accurate measure of steel quality.[illegible]

By the 1920s, specifications became more widely used by other railroads and steel producing firms. However, PRR specifications remained more exacting than the specifications of other roads and technical associations: at the 1921 meeting of the American Railway Engineering Association rail committee, several member railroads confessed that they had obtained price concessions from steel producers in exchange for relaxing rail testing--a practice not condoned by the PRR.[illegible] In 1923, after a series of negotiations with steel producers, the

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[illegible]Pennsylvania Railroad System, Specifications for Carbon Steel Rails, 100-Pound Section, 1915, Box 664, PRR File.

[illegible]In 1922, steel manufacturers increased the additional testing costs from $3.00 to $8.00 per ton, which caused the PRR to abandon this provision: see W. C. Cushing to members of the PRR Rail Committee, January 15, 1923, Pennsylvania Railroad Papers, Box 665, PRR File.

[illegible]C. F. W. Rys to A. C. Shand, March 6, 1923, Box 664, PRR File. The American Railway Engineering Association (AREA) was a technical association whose membership included railway engineers from most of

AREA rail committee decided to further relax its specifications by eliminating the nick and break test which would result in acceptance of dead-setting or piping steel for steel rails. Cushing, chair of the PRR rail committee, again rejected such a change for the PRR; and proposed, instead, to retain the nick and break test "for the purpose of classification so that the rails can be placed in the service for which they are suitable."[90] Such a practice would retain some control over quality and keep costs in line:

> This Company is now paying $1.20 a ton extra for rejection by the nick and break test, and under the specifications which I am proposing it is expected that this extra price can be canceled by reason of receiving the product from the manufacturer, as will be the case with the A.R.E.A. But we will be doing so with our eyes open, making it possible to place these rails in selected places, while in the case of the A.R.E.A. specifications they will be taken blindly and used under the heaviest service.[91]

The PRR often devised more rigorous specifications which were softened by the time they were issued in final form because of threats of increased prices:

> . . . advanced methods of testing . . . to exclude defective material, . . . soon lead [sic] to a stabilized policy on the part of the manufacturer to fix a basic price for steel rails on a generally uniform percentage of acceptable product, and an additional price was set upon each clause in a specification which was likely to increase the percentage of rejection. . . . the Railroad Company must pay an increased price for increased rejection or place its inspection upon a

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the major railroads. The AREA established a rail investigation in the first decade of the twentieth century and was, along with the PRR, in the forefront of steel rail specification-making and improvement efforts.

[90]W. C. Cushing to members of the PRR Rail Committee, January 15, 1923, Box 665, PRR File.

[91]W. C. Cushing to members of the PRR Rail Committee, January 15, 1923, Box 665, PRR File.

classification basis and use the lower material in selected inferior service.[92]

For example, the proposed 1923 specifications increased the allowable silicon content and stiffened the requirements for the drop test. The PRR worked with Carnegie Steel to develop these specifications. Carnegie rolled 1,000 tons of open-hearth steel rails under the proposed specifications and 2,000 tons under the existing specifications, and reported that, under the proposed specifications, there would be an increased number of rails with piping and surface defects, and an increased amount of material rejected on the basis of the stiffened drop test. Rail prices would have to be increased, according to Carnegie's Rys:

> . . . there is no question but that the desired composition in the proposed specification, the requirement of testing rails head down, and the requirement of two blows instead of one, with additional rejection of partial breaks, will very materially increase the cost of production under this proposed specification. In addition to that, there will have to be considered the cost of adding the silicon. . . . it is important that your company make a thorough study of the performance of these rails made under the new experimental specification, as it should be interesting to know whether these experimental rails will show an increase in service quality which might justify such an increase in cost of manufacture.[93]

The PRR was often reluctant to integrate its research findings that indicated ways to improve steel into its specifications due to producers' reluctance to change established manufacturing procedures and frequent threats to increase prices. The PRR rail committee identified several possible ways to achieve quality steel rails that were

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[92] W. C. Cushing to members of the PRR Rail Committee, January 6, 1924, Box 665, PRR File.

[93] C. F. W. Rys to A. C. Shand, March 6, 1923, Box 664, PRR File.

not included in the proposed 1923 specifications.[94] When the new specifications were issued in 1924--specifications which represented 'state of the art' steel rail metallurgy, the PRR acknowledged that the new specifications would still not guarantee quality rails:

> . . . it does not seem likely that minor changes can be expected to bring about any material improvement in the manufacture of carbon steel rails.
>
> It would seem that in order to bring about a radical change in rail steel to meet the advancing severity of traffic conditions there must be a decided modification of the structure which will produce a tough steel of much higher elastic limit, in order to resist the tendency to fracture and to break down in structure under the loads.[95]

To summarize, then, specifications represented the codification of only some of the PRR's research into quality rail steel. Many metallurgical findings were too tentative to be placed in specifications that would be used for contractual arrangements with steel producers; moreover, the PRR was somewhat reluctant to pay higher prices for rails which may have hindered their own efforts to get the best quality rails. Finally, specifications alone would not produce quality steel; more concerted industrial research efforts would be necessary. Thus, the preceding examination of PRR rail specifications is not a complete history of PRR research into rail steel. Many significant improvements in rail steel emerged from the PRR's related investigations into, and experimentation with, steel rails over the first three decades of the

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[94]These included heat treatment and the sinkhead process. Chairman, PRR Rail Committee, to members of the PRR Rail Committee, July 12, 1924, Box 674, PRR File.

[95]Chairman, PRR Rail Committee, to members of the PRR Rail Committee, July 12, 1924, Box 674, PRR File.

twentieth century--improvements that were not always put into specifications.

d. The PRR's Steel Rail Investigations

By the 1910s, it became apparent to the PRR that its specifications and testing methods were insufficient to protect it from failed rails. The PRR launched a major steel rail investigation that differed in intent, if not in form, from its efforts to make specifications for steel rails. The PRR attempted to determine the chemical composition and physical characteristics required to make better quality steel rails, as opposed to merely devising more rigorous physical tests. More importantly, the PRR came to recognize that increased research efforts would be needed to obtain better rails, through cooperation with steel producers, and they became active participants in--in fact, leaders of--a broad based ongoing cooperative industrial research program aimed at determining the appropriate qualities of rail steel.

The PRR participated in efforts to improve steel rails in several arenas. Its laboratories pursued in-house investigations, cooperating with a number of steel producing firms. At the same time they actively participated in studies carried out by such technical associations as the American Society of Testing Materials (ASTM)[16] and the American Railway Engineering Association (AREA). In the process they hastened

[16]The efforts of the American Society for Testing Materials will be treated in depth in Chapter 4.

the transition from rule-of-thumb methods to scientific methods in the manufacture and processing of steel.

Industrial research into steel rail manufacturing by the PRR was prompted by the increase in rail failures, and the wrecks they caused, after 1908.[”] Alarmed by the increasing rate of failures, as well as controversy over the cause of a new type of rail failure identified as transverse fissure,[”] in 1912 PRR president Samuel Rea established a special in-house PRR committee on steel rails. This committee was to look for ways to improve rail steel: Rea directed the committee that "even heavier rails will not cure the situation without improvements in quality . . . . we should actively experiment with larger and heavier tie plates and better fastening and improved support for the track."[”]

The initial task of this PRR committee was to examine failed rails for evidence of possible manufacturing problems, and to study actual manufacturing processes used by various rail producers. The first study revealed that the majority of failed rails had been produced by just three firms: Lackawanna, Bethlehem and Maryland. Finding wide variations in their manufacturing practices, the PRR concluded that

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[”]In 1908, there were 4,845 failures; in 1909, 422 failures; in 1910, 4,769 failures; and in 1911, 1,402 failures. Most of these were web or head failures, so-called because the failure occurred in either the head or the web of the rail: see "Records of President's Committee on Rail Failures," Box 664, PRR File.

[”]Transverse fissures were characterized as "silvery oval spots" in the steel, caused either by manufacturing defects or by excessive loads. See AREMWA, Proceedings, Volume 14, p. 413.

[”]Samuel Rea to W. W. Atterbury, December 8, 1913, Box 664, PRR File.

faulty manufacturing processes were responsible for most rail failures.[100] A second study recommended major improvements to every area of rail manufacture. Gibbs, chair of the PRR rail committee, observed that the PRR would like to change its specifications to reflect these recommendations, but that it was

> . . . hampered continually by the attitude of the steel manufacturers in opposing changes, because of greater cost and the necessity for considerable reconstruction of present mills.[101]

As transverse fissure failures became more frequent, the PRR began to compile more evidence that faulty manufacturing practices were responsible. C. D. Young, head of the PRR testing department, speculated that transverse fissures were caused by faulty manufacturing techniques and recommended changes in manufacturing practices to correct the problem.[102] In the 1910s, the PRR conducted a major steel

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[100] F. N. Pease to A. W. Gibbs, December 11, 1913, Box 665, PRR File.

[101] W. C. Cushing to G. L. Peck, December 15, 1913, Box 665, PRR File. Recommended changes in mill practice included: requiring a minimum of eight minutes for self-cleansing of steel at the furnace; requiring that the ingots be inserted big end down in the reheating furnace (this practice was opposed by the steel manufacturers because it was more difficult to strip the ingot); and cooling the rail before the last five passes through the rolling mill to 900 degrees C, and to a finishing temperature of less than 700 degrees C. In reviewing the report, the PRR's Cushing observed that this was not the first time that the railroad had called for changes in steel manufacturing: "these improvements have been resisted by the manufacturers, as interfering with the capacity of the mill and increasing the cost of production. The greatest effort of the railway engineers, therefore, has been concentrated on improvements in rail testing."

[102] As Young noted: "one of the predominating features found in all of the rails with transverse fissures is the presence of slag close to what we think is the start of the defect. We, therefore, believe that . . . this entrailed slag is the fundamental cause for the defect in connection with the chemical and physical properties which the steel possesses." See Engineer of Tests to J. T. Wallis, July 24, 1912, Box 665, PRR File. Young found authoritative support for his argument in

rail investigation on transverse fissures and confirmed Young's speculations. Failed rails with transverse fissures were classified by manufacturer and tested to see if they conformed to PRR specifications in force at the time the rails were purchased: of eighty-two rails, fifty did not meet specifications. The failed rails were then analyzed under the 1914 PRR specifications, and again, the results showed that a large group of the failed rails did not comply with PRR specifications.[103]

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an article by Robert Job, a noted metallurgist and vice-president of an independent testing firm, which placed the blame for transverse fissures on rail manufacturers: "it has been clearly demonstrated that the cracks . . . are not in the rails when rolled . . . . we have found the defects both in Bessemer and in open-hearth steel, and in high carbon as well as in low carbon steel. In every case we have found porosity, segregation, or other evidence of defective manufacture in the steel." See Robert Job, "Internal Transverse Cracks and Fissures in Rails," Railway Age Gazette, Vol. 56., No. 6, p. 266. Young reviewed the Job study and informed him that the PRR results were in substantial agreement with Job's own analysis: ". . . when transverse fissures are found in rails you can usually find that the steel has been improperly made, in that there is present in decided quantities slag inclusions of some character, generally as manganese sulphide, iron oxide, or some others. This I have found to be the case in our laboratory." See C. D. Young to Robert Job, March 13, 1914, Box 665, PRR File. The PRR made a specific suggestion for changing the manufacturing process: reducing the chemical hardening constituents of the steel in order to restore the ductility of the steel. See F. N. Pease to A. W. Gibbs, December 11, 1913, Box 665, PRR File.

[103]In one test of nineteen failed rails with transverse fissures, it was determined that thirteen rails had been supplied by Bethlehem Steel, and four by Pennsylvania Steel. In a second test of eighty-two transverse fissures, rails were categorized according to manufacturer and whether the material would have been accepted under the existing PRR specifications at the time of purchase. Bethlehem Steel accounted for half of the failed rails; sixty percent of these failed to meet specifications: "they further were the worst offenders, so far as their percentage of material which should have been rejected, is concerned." Cambria rails accounted for sixteen percent of the failures, forty-four percent of which failed to conform to specifications: "this being the best showing of all the manufacturers, in the sense that more than half of the Cambria rails examined had met the specs at the time of manufacture." The Pennsylvania Steel Company was responsible for sixteen percent of the failed rails, seventy-seven percent of which did not meet specifications. Lackawanna was responsible for nine percent of

Based on these results, Young commented, first, on the manufacturing processes of Bethlehem Steel, the worst offender:

> . . . it is seen that not only is the Bethlehem Steel Company the worst offender in the production of steel which developed transverse fissures, but also it furnished 5 rails which, so far as the chemical and physical properties are concerned, do not indicate any special reason for this weakness in the steel. We are inclined to believe, therefore, that either their mill practice, such as not reheating the blooms, cambering too cold, or the treating of the ingots in the soaking pits, has some bearing upon the character of steel which will develop this defect;[104]

and second, on transverse fissures in general--they were not caused by excessive wheel loads, as steel producers claimed. Rather, the failures were due to specific mill practices and "great laxity in following the specifications."[105]

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the failed rails; and made "a poor showing, so far as their mill analysis is concerned, having 85.0 per cent of the material failing to come within the specifications." See "Analysis of nineteen failed rails," PRR test department, 1912-16; and Engineer of Tests to J. T. Wallis, July 18, 1914; Box 665, PRR File. In the second study, high carbon steel, which by 1914 was permissible only for heavier rails, accounted for sixty-two percent of the rail failures. The 1914 PRR "A" specification permitted high carbon steel rails for heavier rails; these had accounted for sixty-two percent of the rail failures. It was determined that the high carbon/low phosphorus combination, tended "to bring about a condition of the steel which makes it subject to development of these internal defects." See Engineer of Tests to J. T. Wallis, July 18, 1914, Box 665, PRR File.

[104]Engineer of Tests to J. T. Wallis, July 18, 1914, Box 665, PRR File.

[105]Engineer of Tests to J. T. Wallis, July 18, 1914, Box 665, PRR File. As Young observed, "I find that Cambria Steel Company, Pennsylvania Steel Company, Carnegie Steel Company, and Illinois Steel Company, are mills which reheat the blooms before they go through the rolling process, whereas at Maryland Steel Company, Lackawanna Steel Company, and Bethlehem Steel Company, this is not the case. It would seem to me that if the rails were rolled direct from the ingot, as is the case at these latter places, there would be a tendency for the steel in the rolling to be considerable [sic] hotter on the inside than on the surface and thereby, tend to start a defect which might ultimately result in a weak structure where transverse fissures might start and this tendency would probably be increased if the finished rails were rolled or

The PRR test and chemical departments began to investigate ways to manufacture quality steel and to eliminate transverse fissures. But producing firms balked and the PRR was relegated to its usual approach: "the best thing which can be done by the railroad company is to modify their specification."[106] Shortly thereafter, the special investigation into transverse fissures was suspended: the PRR investigations had shed

> all the light which such investigation can afford . . . . in the future we will select for study only such failures as give promise of developing something new or throw a new light on the cause of rail failures.[107]

But in the 1920s rail breakages were still occurring: between 1923 and 1926, there were 45,416 failures of rails in the PRR tracks;[108] significantly, there were considerable failures in the newer and heavier

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cambered at too low a temperature." The PRR prepared an analysis of the Bureau of Standards' report on the N.Y., N.H., and H.R.R. wreck that concluded that transverse fissures were attributable to excessive wheel loads and that the Bureau's study ignored the fact that the chemical analysis of these failed rails did not conform to the specification under which they were purchased. These rails were also manufactured by the Bethlehem Steel Company.

[106]Engineer of Tests to F. N. Pease, November 28, 1914, Box 665, PRR File. Yet the PRR continued to investigate possible changes in manufacturing techniques: Young, referring to a 1916 Iron Age article, raised a question with his supervisor, F. M. Waring, as to the "considerable number of 125 lb. rails removed from track due to transverse fissure. I think it would be well to find out if these were gagged in 30" or 42" span gags . . . . If we have found out that the gag is stressing the material so as to produce transverse fissures, would you recommend eliminating the gag and using cold rolling to straighten the rails?" See C. D. Young to F. M. Waring, August 1916, Box 665, PRR File.

[107]W. G. Cyhe to A. W. Gibbs, n. d. (circa 1917), Box 665, PRR File.

[108]In 1923, there were 10,454 failures; in 1924, 12,638; in 1925, 10,949; in 1926, 11,375. See W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674.

130-lb. sections. The cause of transverse fissures remained mysterious: the "cause. . . is not explained by the usual laboratory investigation."[109] The PRR re-opened its investigation but this time, emphasized a broader-based cooperative effort with the Bureau of Standards, the rail mills and other railroads:

> Knowledge upon manufacturing features are in the possession of one party. How the material behaves is known to the other party . . . . A more logical method of procedure could hardly be suggested than the inauguration of joint efforts who are already most familiar with the subject matter. Laboratory facilities and their personnel are at hand in the present equipment of the steel mills and railroads.[110]

The Bureau organized the investigation as a cooperative effort between two railroads, the Atchison, Topeka & Santa Fe and the PRR, and one steel producer, U. S. Steel (its Gary and Carnegie laboratories), to determine whether manufacturing conditions were responsible for causing transverse fissures. This effort was hailed as a major cooperative study:

> The joint efforts of the above laboratories with their superior facilities for settling this fundamental question should without a doubt furnish a final reply to the query whether there is or is not a [sic] abnormal condition or state at the nuclei of transverse fissures, and whether rails can be furnished or [sic] any grade of steel that will sustain present wheel loads and endure present track conditions with immunity from fracture.

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[109]W. C. Cushing to members of the PRR Rail Committee, January 16, 1924, Box 665, PRR File.

[110]W. C. Cushing to Samuel Rea, August 1, 1923, Box 665, PRR File. Throughout the 1910s the Bureau of Standards argued that transverse fissures were caused by railroad practice and not by manufacturing problems. Their explanations for faulty railroad practice included: insufficient rail weight, insufficient abrasive resistance from the rail wheels, and the 'cold rolling' effect of the wheels on the head of the rail. Their proposed solution was "proper regulation of wheel loads."

. . . .

> Each of these laboratories will be requested to carefully examine, microscopically, the structure and metallographic condition of the steel at the nuclei of the fissures. . . . The findings of this inquiry concurred in by each laboratory should at least be the means of settling this one fundamental question so far as information can be acquired upon this subject, after which the next logical question will be proposed for joint examination and solution.[111]

Presumably these later cooperative efforts reduced both the rate of rail failures and the acrimony between rail producers and consumers.

Throughout the 1910s and 1920s, a major activity of the PRR test department was testing failed rails. Such testing activity promoted incremental changes in steel: through testing, the relationship between the presence of certain chemical elements in the rail steel and rail defects was uncovered. From the point of view of the PRR, it was easier to change testing procedures than to change manufacturers' processes; and by changing testing procedures, they became more scientific in their testing and more knowledgeable about steel. Early on, only the simple drop test was used to test failed rails--a test of dubious scientific merit. Although the drop test was not abandoned, it was gradually supplemented with more complex tension and bend tests.[112]

During the 1910s, the PRR conducted significant research into testing techniques and experimented with an entire battery of tests: new

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[111]James R. Howard to J. de N. Macomb, May 12, 1924, Box 665, PRR File.

[112]The drop test was described as "crude and faulty and not sufficient for judging the quality of the steel." The new tests could actually determine the grain and slag content of the steel in the rail. See W. C. Cushing to G. L. Peck, December 15, 1913, Box 665, PRR File.

techniques of etching and photomicrography; Brinell hardness and bend tests; and increasingly complex chemical analyses; much of this research was carried on in cooperation with producers and other interested groups.[113] The bend test resulted from efforts to find a better technique for scientific determination of physical characteristics of rail steel in traffic: the PRR asked manufacturers in 1916 to cooperate "to learn what the substitution of this test for the present physical requirements would mean to them in a more uniform product and one more nearly meeting the requirements of our service."[114] The etching test as well was developed through a cooperative effort with Bethlehem Steel in 1919 and was motivated by the firms' mutual desire to devise a new method of detecting defective steel.[115] In 1920 Chief Chemist Pease proposed a new chemical test for segregation, although he noted that steel producers might object to this new procedure as "as more care is required to avoid breaking a 1/4-inch drill than is the case with

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[113]In one such analysis, the PRR chemist reported that the rails "contain an appreciable amount of nickel and chromium; not knowing the history of these rails at the mill, we are merely calling your attention to the possible source of the higher average stresses in these rails." J. F. Fetterley to J. T. Wallis, n. d. (circa 1916), Box 665, PRR File; and also Engineer of Tests to J. T. Wallis, February 18, 1914, Box 663, PRR File.

[114]J. T. Wallis to C. D. Young, November 10, 1916, Box 664, PRR File. The quick bend test was believed to yield useful information on physical characteristics as elastic limit, stiffness, load corresponding to deflection, ultimate load, toughness, deflection at various loads, and total elongation at ultimate load. Also, the quick bend test could provide a graphic record of a rail during a test and useful data on the condition of the material at the point of fracture. By contrast, the drop test provided information on the elongation for each blow of the tup, the number of blows that it took to break the rail at given heights of the drop, and information on the condition of the material at each point of fracture, and the brittleness of the steel.

[115]A. W. Gibbs to J. T. Wallis, February 14, 1919, Box 665, PRR File.

a 5/8-inch drill."[116] In 1924 the PRR test department participated in a cooperative study of a new testing device--the magnetic detector--devised by James Howard of the Bureau of Standards, believed capable of detecting transverse fissures without destroying the test piece.

Many of these new tests were implemented by the PRR in the late 1910s. The PRR participated in an AREA investigation of transverse fissures in 1917 and 1918 and used its new chemical and physical tests --the quick bend test, the tensile test, the Brinell test, scleroscope readings, and microscopic exams; however, it obtained no definitive results. In 1919 the PRR conducted an extensive analysis of rail section designs, again using a variety of new testing procedures to determine whether design affected internal stresses in new rails, which allowed the PRR to conclude that section design was unrelated to these internal stresses in failed rails.[117]

Although these additional tests helped the PRR to identify poor quality steel before failures occurred, the increasing number and complexity of tests increased rail costs. For example, Pease noted in 1920 that the proposed changes would require an increased number of both laboratory cars and rail chemists, and

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[116] F. N. Pease to A. W. Gibbs, April 7, 1920, Box 665, PRR File.

[117] General Superintendent Motive Power to R. Trimble, n. d. (circa 1917-18), Box 665; Test Department, PRR, to R. Trimble, November 22, 1917, Box 665; and Engineer of Tests to J. T. Wallis, March 28, 1919, Box 663; all in PRR File.

> . . . to carry these chemists on our roll when no rails were being rolled, as it is impracticable to attempt to obtain chemists on short notice and for temporary work.[118]

In 1920, it cost $15.25 per failed rail to perform the various physical tests--additional costs that did not yield better steel, only more information about defective steel. Many of these additional tests were eventually found to provide little useful information and were discontinued, reducing the tests used regularly to just four: deep etching, chemical analysis, the Brinell hardness test, and sulphur print.[119]

Because neither additional physical tests nor more rigorous specifications had succeeded in obtaining better steel, the PRR initiated efforts to improve manufacturing methods and to obtain better steels. Between 1915 and 1930 a number of investigations were conducted into new rail steels and new rail manufacturing techniques--including manganese steel rails, vanadium rails, electric furnace rails, sinkhead rails, and heat-treated rails. These investigations relied on cooperation from steel manufacturers, through which much information about new metals and new production techniques was diffused throughout the steel

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[118] F. N. Pease to A. W. Gibbs, April 7, 1920, Box 665, PRR File. As Pease noted, nine to fifteen chemists would be required for each laboratory car, as the mills ran twenty-four hours a day; thus it might be "advisable for the present, on the ground of economy, to use the laboratory car which we now have as advantageously as possible, and have the chemical inspection of the balance of the rolling taken care of by the mills. . . . This method is not quite as satisfactory . . . . the results obtained by the mill chemical inspection, however, in the cases where this method was followed were fairly satisfactory, only a few heats being accepted which would have been rejected by our own results."

[119] Engineer of Tests to A. W. Gibbs, June 5, 1920, Box 665, PRR File.

industry. Throughout the PRR carefully considered the economic benefits of improved rails. For example, alloy steel rails yielded positive performance results yet were costly, while heat-treated rails showed a similar increase in rail quality at smaller cost.

The earliest investigations were directed at alterations in manufacturing techniques for plain carbon steel rails. In 1915 the PRR studied "cold-rolling" to see if it could reduce segregation and increase hardness; however, there appeared to be

> little, if anything, to be gained in the cold rolling of the blooms, although there is an indication . . . that the material rolled from the cold blooms has a less wide variation than that rolled from the hot blooms.[120]

Another study examined the practice of straightening rails in the gagging press to see if this practice induced rail failures, with inconclusive results.[121] A third investigation examined the differences in rails finished with one of two techniques: cooling rails and then reheating them, or rolling rails directly from the hot blooms. The six regular suppliers of steel rails for the PRR each produced 1,000 tons of rails using both methods, but the PRR found no real difference in service from the two sets of rails.[122] A fourth study, a 1927

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[120] C. D. Young to J. T. Wallis, April 5, 1915, Box 663, PRR File. The PRR's new 1915 specifications had already caused some steel producers to take some steps to reduce the amount of segregation in steel, and, therefore, some of the differences between hot- and cold-rolled steel which might have existed earlier had already been eliminated by the PRR's new specifications.

[121] W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File.

[122] W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File. "However, a careful study of one of these rails in 1921 indicated that the reheated rails had a slightly lesser predisposition to cracks and transverse fissures."

cooperative effort between the PRR and Carnegie Steel, studied the manufacturing process used for carbon steel rails; in this effort, a PRR representative was invited to the Carnegie plant to witness the rolling of rails and was even asked to make comments about possible improvements in the manufacturing process.[113]

During the 1910s and 1920s, the PRR also investigated the new steels--alloy and heat-treated steels--and was able to induce producing firms to cooperate. Experiments were conducted with a wide variety of alloy steels--manganese, nickel, nickel-chromium, titanium, aluminum, silicon, and vanadium; and various new production techniques--electric furnace, sinkhead process, and heat-treatment. Rail producers supplied various experimental rails.[114]

The study of alloy materials began in 1899 with the installation of experimental silicon steel rails in track.[115] During the 1910s, the PRR experimented with a variety of alloy steel rails. In 1909 the PRR began an investigation of vanadium steel rails and requested samples from Carnegie Steel, Crucible Steel, Bethlehem Steel and Midvale Steel for a

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[113]F. M. Waring, "Minutes of the PRR Rail Committee," May 4, 1927; Box 674, PRR File.

[114]W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File.

[115]This was a good example of technological diffusion, as the PRR obtained the idea for this experiment from the recently published research of the English metallurgical engineer, C. P. Sandberg, who recommended the use of high-silicon steel. However, the PRR learned that the first rails used were not really high silicon steel, "as the mill had not succeeded in putting in the required quantity, and further consideration and inspection were abandoned." See W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File.

series of tests: vanadium steel appeared to have remarkable strength.[116] Experimentation with vanadium continued in 1915 with the American Vanadium Company supplying samples of carbon-vanadium steel.[117] The PRR tested the new material and found superior physical properties--these were really "the first tests which we have ever made in which we could find improved physical properties from the addition of vanadium alone."[118] In 1911 the PRR initiated studies of silicon rails and manganese rails: U.S. Steel supplied high silicon steel rails and Manganese Steel Rail supplied experimental manganese rails: both gave good results in brief trials.[119] In 1912 the PRR launched an investigation of titanium steel rails, prompted by Titanium Alloy Manufacturing Company's claim that titanium rails had many beneficial

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[116] Correspondence to Carnegie Steel, October 15, 1909; to Crucible Steel September 15, 1909; to A. D. Mixsell, Bethlehem Steel, September 15, 1909; and to Midvale Steel, February 24, 1910; all from Engineer of Tests; Box 659, PRR File. See also G. B. Kochs to E. D. Nelson, September 22, 1910, Box 659, PRR File; L. Norris to S. Porcher, n. d. (circa 1912), Box 665, PRR File;

[117] F. M. Waring to C. D. A. Pease, July 9, 1915; C. D. A. Pease to F. M. Waring, December 18, 1915; F. M. Waring to J. T. Wallis, January 4, 1916; all from Box 659, PRR File.

[118] F. M. Waring to J. T. Wallis, March 21, 1916, Box 659, PRR File. In 1915, G. L. Norris, metallurgical engineer from American Vanadium Corporation, informed the PRR that a new vanadium material had been developed especially for locomotive axles, crank pins, and piston rods, with beneficial properties. These included the fact that the elastic limit of the steel was twenty-five percent higher than for ordinary annealed carbon steel, and that the steel met all specifications set by the Master Mechanics' Association: see G. L. Norris to C. D. Young, March 13, 1916, Box 659, PRR File.

[119] Engineer of Tests to W. S. Potter, April 17, 1912; and Engineer of Tests to J. T. Wallis, August 29, 1912; Box 663, PRR File.

qualities and requested that Titanium provide sample titanium rails produced under PRR specifications.[130]

Experimentation with alloy rails continued during the 1920s. By 1927, the PRR concluded that high silicon rails provided no advantage in terms of strength, elasticity, or ductility;[131] and efforts turned to the study of manganese rails. These experiments were hindered during World War I due to the scarcity of manganese; even by 1923, manganese rails remained high-priced and were used only on sharp curves on heavy traffic lines.[132] Active experimentation started again in 1924 with "intermediate high" manganese steel rails: Illinois Steel supplied manganese rails that were placed in heavy traffic and appeared to be markedly superior to regular rails.[133] The PRR requested more of these rails because "despite their greater cost, the "toughness and

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[130]Titanium claimed that their ferro-titanium rails were less seamy than untreated plain carbon steel rails, and had much less segregation than untreated rails. See C. H. Strand to F. M. Waring, November 26, 1913, Box 664, PRR File. Waring commented that if the Titanium claims were correct, and if steel companies "can get more of their rails accepted on the PRR specification by titanium treatment as this report indicates, they will soon resort to it, and we will find titanium in our rails." See F. M. Waring to C. D. Young, March 31 1914, Box 664, PRR File. Titanium produced its first titanium rails in 1915 under the PRR specification, tested these rails extensively, and reported the results in a series of bulletins, highlighting two noteworthy results: in one test, only thirty-seven percent of the standard open-hearth rails tested passed the existing PRR specification, while ninety-three percent of the Titanium rails passed; in a second test, titanium steel rails yielded only half the failures of untreated steel rail. See Titanium Alloy Manufacturing Company, "Rail reports, Bulletin No. 5," Box 664, PRR File.

[131]W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File.

[132]W. C. Cushing to members of the PRR Rail Committee, January 15, 1923, Box 665, PRR File.

[133]W. C. Cushing to C. F. W. Rys, December 19, 1924, Box 674, PRR File.

resistance of Hadfield or High Manganese steel . . . was considered very desirable and of sufficient value to pay the additional high cost of $155.00 per ton as against the basic price of $43.00 per ton for Carbon Steel rails."[134] By 1927, however, the PRR's experience with manganese produced a different conclusion: the low elastic limit of manganese steel was offsetting the benefits of longer lasting rails, and experiments with manganese rails were discontinued.[135]

Throughout these investigations into alloy steel rails, Chief Chemist Pease argued that he would not favor any change in PRR specifications until more experience had been gained with these new rails. The new alloy rails were more costly than plain carbon rails: vanadium in particular was relatively scarce and expensive and the PRR was reluctant to conduct further investigation. Moreover, the PRR decided that "for less money than what these people are asking equivalent properties can be obtained in carbon steel by proper treatment."[136]

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[134]W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File. See also Engineer of Tests and Chief Chemist to J. T. Wallis, January 30, 1925, Box 674, PRR File.

[135]W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File.

[136]Engineer of Tests to J. T. Wallis, September 10, 1914, Box 665, PRR File. See also F. N. Pease to A. W. Gibbs, December 11, 1913, Box 665, PRR File. There were substantial discrepancies between the mill's chemical analysis and the PRR' chemical analysis. See Engineer of Tests to J. T. Wallis, September 10, 1914, Box 665; Engineer of Tests to J. T. Wallis, August 29, 1912, Box 663; and C. D. Young to J. T. Wallis, October 11, 1916, Box 659; PRR File. In 1916, Young informed Norris that the PRR was not in the position to take up further tests of vanadium steel at that time. See C. D. Young to G. L. Norris, October 12, 1916, Box 659, PRR File. Young remained intrigued by the possibilities of vanadium steel and requested a close associate of his, E. F. Kenney, metallurgical engineer at Cambria, to send him any information he might have on

As well, various investigations into improved manufacturing processes were conducted during these same two decades. A number of experiments were conducted in the 1910s with sinkhead process rails--a steel-making process long used for guns and other small steel products required to provide superior quality steel. The first sinkhead rails manufactured were obtained in 1915 from the English Sheffield works and Cambria Steel and were studied in a cooperative effort with the Bureau of Standards in the early 1920s. These early rails had a significantly lower failure rate, and by 1927, sinkhead rails had given "exceedingly good results in track service, the failures being many fewer than of the ordinary carbon steel rails."[137] Yet these rails became too costly when Cambria increased the price for sinkhead-process rails in 1927.[138]

A major effort of the PRR's research concerned heat-treated rails. The PRR became interested in the heat-treatment process in the 1910s

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comparisons of ingots made via the sink-head process with vanadium ingots; he promised that "this information is for my personal use only." See Engineer of Tests to E. F. Kenney, October 27, 1914, Box 665, PRR File.

[137]See W. C. Cushing to members of the PRR Rail Committee, January 15, 1923, Box 665, PRR File. The rate of failures for sinkhead-process rails was 172 failures per 100-miles, versus 415 failures per 100-ton miles for ordinary rails. See also W. C. Cushing to members of the PRR Rail Committee, January 31, 1927, Box 674, PRR File.

[138]The price was increased, even though the English producers, the Hadfield, who had pioneered the process, had claimed that there should be no extra charge for rails made by the sinkhead process "as the percentage of product available for all use is much greater, the rejections claimed in regular practice by the Hadfields being only 10%, while rejections of ordinary steel under our 1915 specifications with the chemical survey amounted in some cases from 35% to 40%." See W. C. Cushing to members of the PRR Rail Committee, January 15, 1923, Box 665, PRR File.

through their study of high-carbon steel as the "next step in advance for the improvement of this grade of material."[139] The PRR cooperated with Cambria and Pennsylvania Steel during 1914 and 1915 in a study of heat treatment.[140] The PRR praised the steel producers for their assistance:

> It is very gratifying that these people are taking an active interest in this problem, as I am strongly inclined to believe that it is the future solution for a great deal of our rail trouble.[141]

Commercial-scale heat treatment remained a technical obstacle for some time. Early tests on Pennsylvania Steel's heat treated rails indicated that "heat treatment will improve the quality of the steel, but the experiments have not developed a section which is desirable for a given weight which will make heat treatment possible."[142] Yet the process looked promising: the

> physical properties of a carbon rail . . . can be increased to a very good advantage in a rail of the proper chemistry by proper heat treatment . . . . this subject is well worth

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[139]As Young noted, "undoubtedly the reason for making the high carbon requirement for the 125 pound experimental was to attempt to obtain wearing qualities. This requirement will undoubtedly accomplish that purpose, but at a sacrifice to brittleness in the steel. It would seem to me that the proper way to obtain maximum wear with a uniform and fairly ductile steel, would be to heat treat for hardness and at the sametime (sic) require for the treatment a proper amount of ductility." See Engineer of Tests to J. T. Wallis, n. d. (circa 1912-15), Box 664, PRR File.

[140]PRR top management actively promoted the heat treatment study: the General Superintendent of Motive Power was quite "anxious . . . to get some information on the heat treatment of steel rails:" see C. D. Young to F. M. Waring, January 19, 1914, Box 663, PRR File.

[141]Engineer of Tests to F. N. Pease, February 16, 1914, Box 663, PRR File.

[142]C. D. Young to F. N. Pease, February 16, 1914, Box 663, PRR File.

further consideration and an effort should be made to produce heat-treated rails.[143]

Analysis of the Cambria rails showed similar favorable results. C. D. Young enthused about the prospect of heat treated rails to his supervisor: "from a laboratory point of view it would appear as if the heat treatment of rails could be made a practicable proposition."[144] E. F. Kenney, metallurgical engineer for Cambria, provided a great deal of assistance in the study of heat treated rails, and even invited Young to come to witness Cambria's heat treatment process in 1915.[145] Heat treatment of rails was not yet commercially feasible on a large-scale basis; yet the significant benefits of heat treatment persuaded the PRR to continue experiments during 1915 and 1916, and they placed another order with Pennsylvania Steel for heat-treated rails.[146] Experimentation slowed thereafter as wartime demand required full use of Cambria's facilities for regular production.[147]

The PRR for a time considered "whether the results obtained thus far are sufficient to warrant us proceeding with some design of a plant

[143]C. D. Young to J. T. Wallis, May 6, 1914, Box 663, PRR File.

[144]Engineer of Tests to J. T. Wallis, July 31, 1914, Box 663, PRR File.

[145]E. F. Kenney to C. D. Young, May 12, 1914, Box 663, PRR File.

[146]PRR top management actively promoted the heat treatment study: the General Superintendent of Motive Power was quite "anxious . . . to get some information on the heat treatment of steel rails:" see C. D. Young to F. M. Waring, January 19, 1914, Box 663, PRR File.

[147]In 1916, with the wartime demands calling on all the resources of the steel producers, Cambria informed the PRR that it was unable to assist in further experiments for the time being: see C. D. Young to F. M. Waring, November 2, 1916, Box 663, PRR File.

for carrying out heat treatment of full length rails."[148] Young requested advice on construction of an experimental plant from Cambria's Kenney in November 1916;[149] however, due to the excessive costs, the PRR eventually postponed these plans and decided instead "to collaborate with one of the steel manufacturers, Bethlehem, for instance, rather than to go into the thing ourselves . . . the final cost of the experiment will be less to us."[150] In 1926, the PRR approached E. F. Kenney, now metallurgical engineer for Bethlehem Steel, about cooperating with the PRR test department. Bethlehem proposed to retool its works to handle heat treatment of rails, at a cost of $600,000 and to supply 30,000 tons of heat-treated rail to the PRR at a premium of $20.00 per ton; in return, the PRR would commit to purchasing at least 10,000 tons of heat-treated steel at this increased price for the next three years. The PRR rail committee recommended acceptance of the Bethlehem proposal, buttressing their recommendation to PRR top management with the past data on the success of heat-treated rail. At the same time, the PRR rail committee agreed not to draw up specifications for heat-treated rail, but to accept them under the existing specifications for ordinary carbon steel, and then to take samples from each lot of heat-treated rails for the PRR labs for special

[148] C. D. Young to F. M. Waring, November 2, 1916, Box 663, PRR File.

[149] Initial estimates for construction of such a plant came to $30,265, and were subsequently revised upward to $56,849, in the first few months of 1917: see C. D. Young to E. F. Kenney, November 15, 1916; E. F. Kenney to C. D. Young, November 20, 1916; R. K. Reading to C. D. Young, March 9, 1917; and C. D. Young to J. T. Wallis, March 20, 1917; Box 663, PRR File.

[150] J. T. Wallis to M. C. Kennedy, May 6, 1926, Box 663, PRR File.

etching, micrography, and other analyses. Bethlehem agreed to experiment with various degrees of heat treatment to produce softer and harder steels so that the PRR could determine which would perform better in service.[151]

Although manufacture of heat-treated rails had not yet been achieved on commercial scale by 1927, experimentation continued throughout the 1920s. In 1927 a set of heat-treated rails supplied by Carnegie Steel were placed in service in an effort to study the heat-treated rails of another supplier. The PRR was "not satisfied that the Carnegie Steel Company is paying enough attention to the manufacture of the steel to provide satisfactory rails that will be worth heat treating."[152] It is noteworthy that heat treatment was considered to be so far superior to other methods of improving steel that much research was conducted even while commercial use of heat treatment remained problematic.

Section 6. The PRR's Cooperative Work with Technical Associations

A final important aspect of the PRR's industrial research was its cooperation with various technical associations. Such cooperative work could foster more rapid and widespread improvement of materials than

[151]Bethlehem would make no other changes in its steel making process save the heat-treating itself: see F. M. Waring to members of the PRR Rail Committee, July 3, 1926, Box 674, PRR File.

[152]"Minutes of a meeting of the PRR Rail Committee," prepared by F. M. Waring, May 4, 1927, Box 674, PRR File.

its individual efforts. The underlying philosophy of the PRR's cooperative efforts was that

> . . . progress could not be made entirely on the basis of laboratory experiments . . . . A number of the scientific societies have sections working on specific problems which are of commercial importance to the railroad company, and our scientific workers also have a certain amount of experience which is of aid to the societies.
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> . . . .
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> We believe that practical methods which give the truth should prevail and are in favor of agreement on methods which will be satisfactory to manufacturers, consumers, and government officials who may find it their duty to look into the cause of accidents. We have, therefore, considered it a duty to cooperate with Scientific Societies in the development of problems of this character which are of mutual benefit to a member of important interests.[153]

Societies with which the PRR worked during the first three decades of the twentieth century included most of the major technical and scientific associations.[154]

a. The PRR's Work with the American Society for Testing Materials

The PRR was most active in assisting and promoting the activities of the American Society for Testing Materials, or ASTM. The ASTM worked through its various committees to establish standard

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[153]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR file.

[154]"Departments of Chemical and Physical Tests," n. d. (circa 1913), Box 661, PRR file. Affiliations included: the American Society for Testing Materials; the International Association for Testing Materials; the American Chemical Society; the Joint Rubber Insulation Committee; the American Institute of Mining Engineers; the Society of Chemical Industry; the American Microscopical Society; the American Society of Bacteriologists; the American Public Health Association; the American Society of Mechanical Engineers; the American Railway Master Mechanics' Association; the Master Car Builders' Association; the Franklin Institute; and the American Association for the Advancement of Science.

specifications that would be acceptable to both producers and consumers and many of its committees conducted research into a broad range of commercial engineering materials. The idea of consuming firms consulting with producing firms--and the idea that such interaction between producers and consumers in making specifications was essential--was first initiated by the PRR in the 1870s, and was introduced to the ASTM by the PRR's Charles Dudley.

The PRR was influential in shaping the research agenda of the ASTM for two reasons. First, the PRR chemical and testing laboratories conducted much of the industrial research for the ASTM.[155] Second, leading individuals in PRR labs also held major posts for the ASTM: up to his death in 1909, Dudley, head of the PRR chemical laboratory, was the ASTM's president, and C. D. Young, head of the PRR testing lab in the 1910s, chaired the ASTM steel committee for many years. By 1914 six other prominent PRR staff members held ASTM memberships.[156]

The ASTM was an important arena for many of the cooperative efforts between the PRR and materials producers. The PRR helped to

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[155]As well, the PRR conducted industrial research for other technical associations, including the Bureau of Standards, the Master Car Builders' Association, the American Rail Masters Mechanics Association, and the American Society of Mechanical Engineers. See Arthur Percy Morris Fleming, Industrial Research in the United States of America (London: Publ. for the Department of Scientific and Industrial Research by Her Majesty's Stationery Office, 1917), p. 15.

[156]Other PRR employees who were prominent members of the ASTM included: W. O. Dunbar, Assistant Engineer; F. M. Waring, Foreman, Physical Laboratory; H. M. Ramsay, Chief Inspector; F. N. Pease, Chief Chemist; M. E. McDonnell, Assistant Chief Chemist; and H. B. Rodman, Chemist; see Engineer of Tests and Chief Chemist, February 14, 1914, Box 661, PRR File.

establish cooperation as a standard operating procedure for the society, although there were some obstacles to be overcome:

> . . . the <u>principle</u> of cooperation between manufacturers and consumers, early recognized as essential to the preparation of standard specifications, was firmly established . . . . However, the idea was new and there was some reluctance on the part of manufacturers to cooperate fully and to meet the consumers half-way. Moreover, consumers as a rule were new-comers [sic] in the field of specifications. Consequently, in spite of numeric balance between the two interests, the charge frequently was made that A.S.T.M. specifications were 'manufacturer's specifications', and many consumers drafted specifications for their own use with more stringent requirements.[157]

Cooperation under the aegis of the ASTM required strong leadership from consuming interests, and this leadership was provided by PRR representatives for many years.[158] The PRR exerted strong influence on the ASTM's steel research agenda because C. D. Young, as

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[157]Secretary, ASTM, to A. L. Johnson, November 2, 1916, Box 669, PRR File.

[158]The importance of the PRR to the ASTM was even recognized by steel producers. By 1912 Charles Dudley had died and the PRR's influence in the ASTM was beginning to wane. E. D. Nelson, metallurgical engineer for Bethlehem Steel, urged C. D. Young, in 1912, to become more active in the ASTM, in an eloquent statement of the importance of cooperative work to both consuming and producing firms, and of the prominent role the PRR had always taken in such cooperative work: "One of the principles on which the Society was founded, and which has brought it success, was to provide a means for a free and full discussion of proposed specifications, including those essentially interested, namely, the Consumer, the Manufacturer and the Engineer. All Committees, which do the real work of preparing specifications, have their membership made up of representative men from each of these three classes. The result has been satisfactory and the Pennsylvania Railroad cannot afford to be out of close contact with this work. It all means better specifications in the general field and economical operations for the manufacturer, resulting in better prices for the Consumer. Not the least of the advantages to the Penna. railroad is the opportunity for contact with men possessed of the latest knowledge in their own lines." See E. D. Nelson to C. D. Young, January 2, 1912, Box 674, PRR File.

chair of the ASTM steel committee in the 1910s, communicated frequently with other steel consumers and steel producers. The ASTM had an early interest in the steel products used by railroads: by 1912, the ASTM had already issued specifications for various steel products of interest to railroads: billet-steel reinforcement bars, quenched and tempered forgings for locomotives, and rolled steel wheels. Many of these steel specifications were drafted in cooperation with other societies: "this cooperation in some instances has resulted in the use by different organizations of substantially the same specifications, a condition much to be desired."[159] In 1916, Marburg, secretary of the ASTM for many years, credited steel consuming interests like the PRR with inducing improvements and standardization in specifications:

> . . . the cooperation between manufacturers and consumers on the committee has been most effective. . . . As a consequence nearly all of the steel specifications of the Society are within as close chemical and physical limits as those of the larger consumers, and are being used more and more throughout the country,--are truly becoming 'standard' specifications.[160]

The PRR influenced specific ASTM investigations as well: a good example was the ASTM steel rail investigation in the 1910s. During that decade a number of rail investigations were underway by individual rail consuming firms like the PRR and by technical associations like the AREA but with few tangible results to date (See Section 5, above). The

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[159]Secretary, ASTM, to A. L. Johnson, November 2, 1916, Box 669, PRR File. Some of the other societies included the Master-Mechanics' Association, the Master Car-Builders' Association, the American Electric Railway Engineering Association, the Rail Steel Bar Manufacturers' Association, and the Society of Automobile Engineers.

[160]Secretary, ASTM, to A. L. Johnson, November 2, 1916, Box 669, PRR File.

ASTM initiated its own investigation in the early 1910s with the end in view to design a specification that would provide better quality rails and yet would be acceptable to both steel producers and consumers. The ASTM investigation was hindered by the same lack of fundamental metallurgical knowledge that hindered the PRR's in-house efforts: during one 1913 discussion about proposed changes in ASTM specifications for steel rails, it was noted that the ASTM sub-committee on rails had done nothing "regarding the revision of specifications for steel rails for some years, because of the unsettled condition; nobody seems to want to take any decided action on this matter."[161]

The ASTM steel rail investigation appeared to be a promising route because it could utilize cooperative industrial research between producers and consumers. E. F. Kenney of Cambria Steel strongly supported the ASTM study of steel rails because both steel producing and consuming interests would be represented. and promised Young, chair of the ASTM steel committee, that he would support such an investigation:

> Personally I think that Committee A-1 should take up the question of the study of steel rails along about the same lines as Mr. Wickhorst has been following up for the American Railway Association. Whether or not it is politic to do this at this time is open to some question. . . .
>
> [I]f we do go into it, I am in favor of going into it thoroughly. If you as Chairman of Committee A-1 will give instructions to the sub-committee to prepare new specifications for steel rails and make a general study of

[161]"Minutes of the ASTM Committee A-1" (on Steel), October 3, 1913, Box 668, PRR File.

> the subject, I will certainly do everything in my power to see that the sub-committee takes the work up at once.[162]

Young directed the ASTM rail sub-committee to proceed by investigating the specifications currently being used by other technical associations and firms, and to consider the physical tests currently being disputed by steel manufacturers and consumers. Another burning question concerned the shapes and sizes of test ingots used by various steel producers, and whether it was necessary to prescribe precise shapes and sizes for test ingots in ASTM specifications. Thus, the ASTM steel rail investigation, at least at its inception, did not move to study changes in steel manufacturing required for quality steel rails.[163]

By 1916 a number of steel rail investigations were underway by steel producers and steel consumers, technical associations and academic researchers. The rail sub-committee was directed by C. D. Young to collect and organize this growing body of information on improvements in rails, and prepare a

> . . . brief statement of other specifications which are being tried, either experimentally, or as new specifications, which involve other specifications than those which are contained in the Society Testing Materials specifications, mention being made of such additional requirements of the specifications which point to the effort of the consumers to obtain better rails, confining, of course, such statements to such orders which cover tonnages larger than, say one or five thousand tons. In this way, Committee A-1 and the Society at large will be kept informed of the progress which is being made in the development of further information which ultimately

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[162]Kenney made the observation that a non-ASTM cooperative effort launched by the presidents of the largest railroads and the presidents of the largest steel companies had borne no fruit. See E. F. Kenney to C. D. Young, September 2, 1913, Box 668, PRR File.

[163]See "Minutes of the ASTM Committee A-1" (on Steel), October 3, 1913, Box 668, PRR File.

> may be reflected in changes in the Society for Testing Materials specifications.[164]

Shortly thereafter, Young established a research committee to keep abreast of all available information on steel rails. However, revisions in the ASTM specifications for carbon steel rails based on the ASTM steel rail investigation were not proposed until 1921.[165]

Another example of how the PRR was able to influence committee work was a 1914 study by the ASTM steel committee. Young asked F. D. Carney to survey the sub-committee on steel castings regarding a proposed change in the sulphur allowance in the ASTM specification for steel castings. Carney completed the survey and notified Young that his sub-committee favored such a change in specifications, but asked for Young's opinion, in his dual capacity as chair of the steel committee and as a representative of a major user of steel castings, before releasing the report to the rest of the steel committee.[166] Young passed the

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[164]C. D. Young to Edgar Marburg, March 15, 1916, Box 669, PRR File.

[165]An influential member of the ASTM, Professor Edgar Marburg, praised this study, and suggested to Young that the rail situation was "one of such prime importance that I think some explicit reference to it should be made in every annual report of Committee A-1." See Edgar Marburg to C. D. Young, March 14, 1916; C. D. Young to Edgar Marburg, March 15, 1916; C. D. Young to Edgar Marburg, March 13, 1916; Box 669, PRR File. The new specifications retained both the check analysis and use of the drop test, for testing the chemical and physical characteristics of the rail steel; however the test to destruction and the exhausted ductility test had been eliminated. See "American Society for Testing Materials, Standard Specifications 'Class B' for Carbon Steel Rails, Proposed by Sub-Committee 1 of Committee A1," January 14, 1921, and "American Society for Testing Materials, Standard Specifications, Class 'A'. for Carbon-Steel Rails, Serial Designation: A1 - A4. Adopted 1901; Revised 1907, 1908, 1909, 1914; both Box 668, PRR File.

[166]F. D. Carney to C. D. Young, February 19, 1914, Box 668, PRR File.

report on to Pease, chief chemist for the PRR who recommended no change in the specifications; and, as there was growing evidence that high sulphur content in steel might be a problem, Young informed Carney that he remained "personally strongly opposed to any change in this requirement."[167]

When Carney suggested a different modification to the specification, Young again passed the request on to Pease; and again Pease vetoed the change. Young again informed Carney that, as chair of the ASTM steel committee, he would not recommend such changes in the cast steel specifications, based on the PRR's experience. In both cases, the PRR was able both to employ its considerable in-house resources and to exercise considerable influence in order to keep the ASTM specification to the liking of steel consumers.[168]

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[167]C. D. Young to F. D. Carney, February 20, 1914, Box 668, PRR File. Pease had informed Young that, "in nearly all cases the sulphur and phosphorus are well below the specification limits . . . . It would seem, therefore, that there is no occasion for making an absolute maximum for sulphur of .055 in order to diminish the possibility of some rejection of material which is not what would be considered satisfactory:" see F. N. Pease to C. D. Young, February 20, 1914, Box 668, PRR File. Young accordingly informed Carney that "I would certainly, as a member of Committee A-1, unless evidence is produced, either that it is exceedingly difficult to meet this requirement, or that high sulphur does not have any injurious effects upon the castings, be against taking a step of this kind which I feel would be in the wrong direction."

[168]This time Carney proposed that the specification be modified to allow for allowances in the form of combinations of elements, so that a joint limit for sulphur and phosphorus would be specified. This time Pease argued that higher individual limits for phosphorus and sulphur, even if the sum of the two was kept below a particular limit, was not advisable, as "if by any chance the sulphur would be unusually low, the phosphorus could be allowed to run up to a figure which we would not consider desirable." See F. N. Pease to C. D. Young, March 2, 1914; and C. D. Young to F. D. Carney, March 3, 1914; Box 668, PRR File.

In 1916, when the steel committee listed its major accomplishments, railroad-related steel products predominated, including specifications for the following: rail-steel concrete reinforcement bars; carbon-steel rails; and steel forgings; as well, such standard PRR goals as standardization of methods for chemical analysis and use of a standard form for specifications were implemented.[169]

Like the PRR itself, the ASTM did not confine its research work to specification-making, but also engaged in industrial research into manufacturing techniques and better materials. Dialogue between producers and consumers in conducting these special investigations was built into the ASTM process and was initiated and guided, to a large extent, by the chairs of ASTM committees; thus the PRR was often able to initiate ASTM dialogue between consumers and producers into new research areas of special interest to the PRR. Young, as chair of the ASTM steel committee, interacted frequently with steel producers in areas of new steel technology.

One example was heat treated steel. During the ASTM steel rail investigation, the PRR was conducting its own initial tests of heat-treated steel. Young acquired heat-treatment test results from E. F. Kenney, fellow ASTM steel committee member and metallurgist for Cambria Steel, in 1915, and shared these test results with other members of the

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[169]These specifications represented hard work by the various ASTM steel sub-committees and the influence of the PRR: the rail sub-committee had begun a study of important developments in the changing rail situation. The steel forging specifications, originally issued in 1905, were reissued in 1914 after a year long investigation, and by 1916 specifications for alloy steel forgings were issued, although the chemical properties for alloy steel to be declared 'standard' were still under review. See Secretary ASTM to A. L. Johnson, November 2, 1916, Box 669, PRR File.

ASTM steel committee.[170] In 1914, Young considered issuing ASTM specifications for heat-treated steel for locomotives, and sent proposed ASTM specifications for heat-treated material to various locomotive materials producers--Baldwin Locomotive Works, American Locomotive Company, Standard Steel, and Carnegie Steel. Wille, the Baldwin representative to the ASTM, responded that the specifications were not representative of existing practice; noted that Standard Steel, American Locomotive, and Carnegie were engaged in ongoing studies of heat-treated alloy steel; and convinced Young that it would be better to wait for their results.[171]

Another area of interest to the PRR that was pursued by the ASTM was alloy steel. Interest in vanadium steel rails on the part of the PRR was sparked by a 1915 discussion of vanadium steel at the ASTM convention.[172] Subsequently, the PRR pushed the ASTM to consider alloys for various steel applications: for example, Young directed the sub-sub-committee on alloy steel forgings to survey steel manufacturers concerning proposed ASTM specifications for alloy steel forgings.[173]

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[170]As Young remarked to Kenney, the "tests on the heat-treated rails are most interesting to me:" see Engineer of Tests to E. F. Kenney, August 3, 1915, Box 669, PRR File.

[171]According to Wille, the British specifications currently in use by his company--specifications "written by the most eminent metallurgists and engineers in England"--were sufficient: see H. V. Wille to C. D. Young, February 10, 1914, Box 668, PRR File.

[172]F. M. Waring to C. D. Young, March 20, 1916, Box 659, PRR File.

[173]One manufacturer noted his firm's ongoing work with alloys and the lack of definitive information to date: "we believe that from the experience of users of alloy steel, it would be practicable at the present time to specify definite chemical requirements for certain grades which

The PRR participated in ASTM committee work as well as directing it--in fact, membership on an ASTM committee required that members be willing and able to perform a share of the committee's research. A good example of the PRR's participation in ASTM research was an investigation initiated in 1920 into the effects of phosphorus and sulphur on steel, a study motivated by concern on the part of many railroad chemists and engineers about sulphur. The joint committee included representatives from the Bureau of Standards, the ASTM, the American Railway Association, the Society of Automotive Engineers, the National Research Council, and various sub-committees of the joint committee were composed of specific steel manufacturers and railroad representatives.[114] Chemical laboratories of the PRR and the Baltimore

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are in constant use, but we are not prepared from our own experience to say just what these specifications should be." See Member of Committee to J. M. Darke, Chairman, Sub-Sub-Committee on Alloy Steel Forgings, November 21, 1916, Box 669, PRR File; and C. L. Warwick to Albert Sauveur, March 16, 1917, Box 665, PRR File.

[114]This concern was, of course, shared by many metallurgists, chemists, and engineers for other consuming and producing interests: at the time, a number of metallurgists contended that sulphur had deleterious effects on steel; but most metallurgists were unable to determine the definite limit on sulphur content for any particular type of steel. See "Statement for Publicity concerning the work of the Joint Committee on Investigation of Phosphorus and Sulfur in Steel," September 15, 1923; and "Sulphur and Manganese in Rivet Steel," Chemical and Metallurgical Engineering, May 31, 1922, p. 1011; both in Box 674, PRR File. Other participating groups included: the Association of American Steel Manufacturers, the Steel Founders' Society, the American Foundryman's Association, the Society of Naval Architects and Marine Engineers, and the U.S. War and Navy departments. See also "Minutes of Meeting of Joint Committee on Investigation of Phosphorus and Sulfur in Steel," June 22, 1020, prepared by C. L. Warwick; "Progress by Manufacture Committee to the Joint Committee on Investigation of Phosphorus and Sulfur in Steel," written by George K. Burgess; and "Minutes of the Sub-Committee on Tests of the Joint Committee on Investigation of Phosphorus and Sulfur in Steel," May 17, 1923; Box 674, PRR File.

and Ohio Railroad performed much of the analytical work and most of the physical tests of the steel--tension, shear, impact, hardness, torsion, and bend tests. However, at the conclusion of this investigation, a leading industry trade journal observed that the investigation had primarily tested methods of testing--"not only their competence but their significance."[115]

b. Other Cooperative Industrial Research Efforts of the PRR

The PRR also cooperated with other technical associations, organizations and official agencies. In some cases the PRR initiated cooperative committees under its own aegis to carry out a large research effort. In these efforts the PRR worked to promote its own research interests, but allowed the cooperating parties access to its research results and worked cooperatively to achieve better steel.

Cooperative efforts with other railroads were typically easy to organize. In a 1913 example, the PRR wished to initiate a study of heat-treated steel for locomotive construction, and formed a special committee with other railroads to study special alloys and heat-treated steel for locomotive construction. One of the cooperating railroads was the Atlantic Coast Railroad Company (ACRR) which agreed to share with the

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[115] "Sulphur and Manganese in Rivet Steel," Chemical and Metallurgical Engineering, May 31, 1922, p. 1011. See also "Minutes of Meeting of Joint Committee on Investigation of Phosphorus and Sulfur in Steel," June 22, 1920, prepared by C. L. Warwick; "Minutes of Meeting of Sub-Committee on Tests of the Joint Committee on Investigation of Phosphorus and Sulfur in Steel," April 10, 1922, prepared by F. C. Langenberg; all in Box 674, PRR File.

PRR its own in-house study on failures in heat-treated axles, commending it to the PRR with the following warning:

> I trust you will treat [it] confidentially to the utmost degree as it contains the names of manufacturers and an inspection bureau. . . . I will send it, therefore, with the understanding that you will use it personally and extract such information as you may desire for the use of your committee.[176]

Another cooperative railroad effort was the American Railway Master Mechanics' Association Committee (ARMMA) on Special Alloys in 1912, chaired by Young. To promote the ARMMA effort, Young surveyed various manufacturers of alloys and heat-treated steel, including Midvale Steel. Interestingly, Midvale representatives announced their preference to work through the ASTM rather than with the railroad group, as the former association "represents a great deal of thought and conference between producer and consumer."[177]

Cooperative efforts between the PRR and steel producers were more difficult to initiate. The PRR proposed a cooperative study in 1927 into transverse fissures with the producer of a rail which had recently

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[176]Correspondence to C. D. Young, January 31, 1913, Box 675, PRR File. The report on heat-treated axles showed one manufacturer in particular to be responsible for many failed axles: the Pollak Steel Company, which actually purchased its forging blooms from an outside source, "and from an inspection of their stock, it was evident that some of them were physically unsound through inherent defects." Other criticisms were made of the Pollak practice--incorrect placement of the fire rods of the pyrometer so as to not show the proper temperature of the axles, and bad quenching practices in regard to the actual heat treatment with respect to the use of water and the temperature. See "Report of Investigation suggested by the Failure of a Number of Heat Treated Carbon Steel Axles, Atlantic Coast Line Railroad Company," issued by Office of General Superintendent Motive Power, February 1, 1913, Box 675, PRR File.

[177]W. P. Barba to C. D. Young, November 29, 1912, Box 675, PRR File.

failed and caused a wreck, Bethlehem Steel;[178] but to secure Bethlehem's cooperation in determining possible manufacturing causes for this failure, the PRR refused to order any more rails unless they came to "some suitable arrangement on the subject."[179] Preliminary investigation by Bethlehem disclosed that nothing unusual had occurred in the manufacture of this rail, although maybe the heat of rails had been rolled "a little too hot."[180] The PRR decided that they needed

> . . . better control of the thermal state of the steel rails during manufacture until finally cool for handling, but as this will require some rearrangement of mill facilities it is necessary to settle as exactly as possible a course of procedure for determining the best way for accomplishing the objects sought.[181]

A detailed examination was made of Bethlehem's manufacturing practices, because the PRR believed the break to have been caused by a mill failure but had no method of detecting such defective steel: however

> [o]ur own laboratory experiments in breaking rails head down have shown the fracture in the head apparently originating from a nucleus which gives a starring appearance, and when such rails have been cut and deep etched we have found shattering cracks. The manufacturers have consistently opposed the making of drop tests with head down, therefore I think we should renew our attack along this line with a view to including such a test in our specification requirements. We would of course have to make a considerable number of additional tests in order to

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[178]The preliminary investigation by the PRR discerned an unusually large transverse fissure in the head of a failed rail produced by Bethlehem Steel. See T. J. S. to M. W. C., July 9, 1927; T. J. Skillman to F. W. Hankins, August 10, 1927; and T. J. Skillman to M. W. C., July 18, 1927; all Box 674, PRR File.

[179]Engineer of Tests to W. C. Cushing, July 29, 1927, Box 674, PRR File.

[180]W. C. Cushing to F. M. Waring, August 3, 1927, Box 674, PRR File.

[181]W. C. C. to T. J. S., August 9, 1927, Box 674, PRR File.

derive data for a specification requirement covering appearance of fracture and procedure for deep etching.[112]

One example of the PRR's cooperative industrial research with government organizations was its work in the 1910s with the Bureau of Standards, a government organization interested in standardization and testing of industrial materials, including steel. In the early 1910s the PRR conducted experimental magnetic examinations of various steel materials, with no conclusive results; but metallurgists began to speculate that magnetic testing might help discern transverse fissure defects. In 1912, the PRR agreed to cooperate with the Bureau of Standards to determine the effectiveness of magnetic testing in determining the physical characteristics of steel and the PRR's F. M. Fahy was dispatched to the Bureau. Fahy was authorized to share all information previously gathered by the PRR test department on magnetic testing and transverse fissures.[113] The PRR also arranged for Fahy and the Bureau's Burgess to go to Maryland Steel to conduct magnetic tests on-site.[114]

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[112]Engineer of Tests to W. C. Cushing, July 29, 1927; Box 674, PRR File. The test pieces were to be cooled using different procedures, and two sets of identical test pieces were to be created so that both Bethlehem and the PRR could conduct the same battery of tests on the ingots: see W. C. Cushing to Earl Stimson, July 27, 1927, Box 674, PRR File.

[113]"The Correlation of the Magnetic and Mechanical Properties of Steels," prepared by F. M. Fahy, March 14, 1916, Box 658, PRR File.

[114]General Superintendent Motive Power to F. W. Wood, January 23, 1913, Box 665, PRR File.

Yet the PRR intended this cooperative effort to be a short-term arrangement; once a method of magnetic testing was worked out, Fahy would return to the PRR labs to apply this new method:

> It was not the intention that Mr. Fahy's work was to be carried along, . . . so as to help him determine questions for the Government in connection with steel rail manufacture so that they may put additional burden on the railroads but rather to Five [sic] the railroads this information in advance of the Government and let them make their own tests.[115]

The PRR insisted that Fahy return after just a couple months: as Young directed, "I think it most desirable that we should close, as promptly as possible, the work which you started on spring steels, in order that we might get some definite date [sic] on this subject."[116] Fahy demurred, stating:

> I think it important to advise you that for two years or more the Bureau of Standards has been preparing to make an investigation of steel rails, and during the past six months have completed their plans for that purpose. They will be glad to cooperate with us in this work, but in any event will actively enter into it early next month. At the risk of appearing persistent in this matter, I would respectfully suggest that the participation of your office would help to insure that the investigation would be conducted in a manner so as to conserve the interests of those concerned in the use of rail steel.[117]

Young requested information on the Bureau's plans so that the PRR could whether it wished to cooperate;[118] upon review, the PRR

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[115]Engineer of Tests to J. T. Wallis, February 5, 1913, Box 665, PRR File.

[116]C. D. Young to F. M. Fahy, March 24, 1913, Box 665, PRR File.

[117]F. M. Fahy to C. D. Young, April 16, 1913, Box 665, PRR File.

[118]C. D. Young to F. M. Fahy, April 19, 1913, Box 665, PRR File.

committee decided that it would continue its own investigation and Young summoned Fahy back to Altoona, reminding Fahy that

> the rail investigation is not a subject that was contemplated when we sent you to Washington, and we do not wish to make investigation of rails through the Bureau of Standards, but prefer to handle such work in our own test department.[189]

The experience did not dissuade the PRR from attempting another joint project with the Bureau later in the decade. In 1919 the PRR dispatched another lab employee, K. E. Hofammann, the assistant foreman of the physical lab, to study deep etchings of rail heads made at the Bureau that had detected "defects which are apparently cracks existing in new rails that have never been in track."[190] However, a PRR report noted that deep etching had not revealed the cause of these defects:

> but since they have been found in new material, it is reasonable to suppose that the causes must be sought in the mill at some time during the rolling of the material. . . . it is hoped to arouse the interest of metallurgists, steel makers and consumers to the end that cooperation may be secured for a thorough investigation into the causes of these defects and the proper remedy that should be applied.[191]

The report was sent to Bradley Stoughton, secretary of the American Institute of Mining Engineers and a noted independent metallurgist.[192]

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[189]General Superintendent, PRR, to F. M. Fahy, April 29, 1913, Box 665, PRR File.

[190]Engineer of Tests to S. W. Stratton, May 3, 1919, Box 665, PRR File.

[191]"Detection of Transverse Fissure Defects in Rails by Etching," PRR Test Department, May 29, 1919, Box 665, PRR File.

[192]"Detection of Transverse Fissure Defects in Rails by Etching," PRR Test Department, May 29, 1919, Box 665, PRR File.

Clearly, the PRR preferred cooperative industrial research efforts over which it had complete charge. For example, in 1927, the PRR was asked to cooperate with a "recently authorized joint investigating committee appointed by the A.R.E.A. and the rail manufacturers"[193] to establish a cooperative effort between the rail mills and the railroads. The director of the committee would be a qualified metallurgist with experience in both steel making and laboratory methods, with the laboratory work to be conducted at a neutral laboratory--the Bureau of Standards or the University of Illinois. The PRR's Waring warned the PRR internal committee that "this subject while not in direct connection with that of the use of heat treated steel nevertheless involves the making of a decision by the Pennsylvania Railroad as to how far it will go in the joint investigation."[194]

By contrast, in 1919, the ASME requested that the PRR participate in an ASME Research Committee Clearinghouse. The PRR did not have a dominant role in the planned committee and thus displayed little enthusiasm: Engineer of Tests F. M. Waring suggested to his supervisor, J. T. Wallis, that such cooperation entailed little more than "forwarding a copy of the final report"[195] and that the PRR ought do no more than that to start. Wallis then notified the ASME, in understated fashion, that

[193] F. M. Waring, "Minutes from a meeting of the PRR Rail Committee," May 4, 1927, Box 674, PRR File.

[194] F. M. Waring, Minutes from a meeting of the PRR Rail Committee, May 4, 1927, Box 674, PRR File.

[195] F. M. Waring to J. T. Wallis, April 29, 1919, Box 667, PRR File.

we are not at this time carrying on any work which might strictly be called research work. Our problems are almost entirely those connected with operating the railroad and are usually attacked from the standpoint of developing some particular information which will be of immediate use to us.[196]

Section 7. Conclusion

As steel consuming firms like the PRR began to insist on better quality steel and different kinds of steel for their products, they found it useful to organize research into the desired characteristics of steel products used by their firms. The PRR became a true industrial research pioneer that conducted substantial research into steel products and processes and helped to spark greater industrial research efforts on the part of many steel producing firms, through its own in-house efforts and through such technical associations as the American Society for Testing Materials (or ASTM). The efforts of the ASTM in promoting industrial research were so important that they will be considered in detail in the next chapter.

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[196]General Superintendent of Motive Power to Arthur N. Greene, Jr., February 2, 1920, Box 667, PRR file.

CHAPTER 4

THE INFLUENCE OF THE AMERICAN SOCIETY FOR TESTING MATERIALS ON INDUSTRIAL RESEARCH IN STEEL

Section 1. Introduction

By 1900, through the efforts of consuming firms like the PRR, specifications were being used to ensure reliability and quality in steel products.[1] As a result, steel producing firms had to meet increasingly stringent specifications for steel products:

> the manufacturer of steel confronted an increasingly stringent set of requirements for steel imposed upon him by a widening set of customers. Each one was likely to be interested in a different property, or, more likely, in different combinations of properties.[2]

Steel producers gradually became accustomed to specifications and, early on, derived some benefit from their use. The industry's major trade journal, Iron Age, praised specification-makers for "bringing order out of chaos in the matter of specifications for materials of construction"[3]

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[1]"It became extremely important to understand such things as the notorious variability of the metal, as well as its precise performance characteristics when subjected to a wide range of new stresses, tensions, and pressures in entirely new applications. Thus the feasibility of employing steel on a large scale, after the innovations that led to its lower price and greater supply, led to considerable research and testing by new classes of users, as well as the steelmakers themselves." See Rosenberg, Inside the Black Box, p. 157; and also "The Commercial Exploitation of Science by American Industry," p. 30.

[2]Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 29.

[3]The Iron Age, August 16, 1900, p. 19.

and predicted that specifications would reduce manufacturing costs by promoting standardization and thus increase American steel exports. A few steel producing firms actually issued their own specifications during this time. One of the first successful efforts to standardize steel specifications was made by the Association of American Steel Manufacturers (AASM) in 1895 when they issued specifications for structural steel;[4] Carnegie Steel also issued early specifications for some steel products.[5]

But conflicts over specifications began to emerge between steel producers and steel consumers in the early years of the twentieth century. Steel producing firms' specifications were criticized by many steel consuming firms as "manufacturers standards,"[6] because they did not meet the more rigorously-defined needs of steel consuming firms. Steel consuming firms and technical associations continued to formulate their own 'consumers' specifications, with important differences between their specifications and producers' specifications. Steel consuming firms relied on specifications as the best means of obtaining quality steel and

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[4] The Iron Age, April 30, 1903, p. 28. The members of this group in 1903 included: American Iron & Steel Manufacturing; American Steel & Wire; American Steel Hoop; Bethlehem Steel; Cambria Steel; Carbon Steel; Carnegie Steel; Central Iron and Steel; Colorado Fuel & Iron; Crucible Steel; Diamond State Steel; Glasgow Iron; Illinois Steel; Inland Steel; Jones & Laughlin Steel; Lackawanna Steel; Lorain Steel; Lukens Iron & Steel; Maryland Steel; National Steel; National Tube; Otis Steel; Passaic Steel; Pennsylvania Steel; Pittsburgh Forge & Iron; Reading Iron; Republic Iron & Steel; A. & P. Roberts; Shelby Steel Tube; Standard Steel Works; Tennessee Coal, Iron & Railroad; Tidewater Steel; and Worth Brothers.

[5] The Iron Age, December 12, 1907, p. 1696.

[6] "Recent Advances in the Standardization of Steel Specifications," The Iron Age, April 30, 1903, pp. 28-29.

regarded them, not as ideals, but as contractual obligations to be met by steel producers:

> . . . Industry is constantly calling for greater efficiency of equipment and this involves materials of superior properties or lower costs, or both. In order to be able to guarantee the performance of apparatus, manufacturers have been obliged to specify definitely the properties of the materials used. The need for a more exact statement of the requirements, and, in many cases, improvement in quality, has been recognized. The most effective means of accomplishing these results is standardization of specifications.[7]

Steel producers argued against the more stringent clauses in specifications; these were obviously drawn up by persons not actively engaged in steel production and lacked essential practical knowledge about steel production:

> . . . If it amused a customer to formulate such things and present them as describing that which is desired to purchase, well and good, but that the products should actually conform to the details of what they considered purely academic requirements was a different proposition. They had been for years engaged in their several occupations and naturally knew more about them than was possible for any outsider.[8]

Consumers' specifications were regarded by most steel producing firms as ideals, and steel consumers were regarded as being unaware of the practical problems encountered by producers in meeting their specifications:

> . . . let them be drawn ever so carefully, and based on the most careful observation, they cannot entirely take the place of and make unnecessary the exercise of initiative on the part of the producer. Specifications have to be not only adapted to the conditions under which the materials are to

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[7]ASTM, <u>Proceedings</u>, Part 2, Philadelphia: ASTM, 1925, pp. 425-26.

[8]<u>The Iron Age</u>, June 26, 1913, p. 1570.

> be used, but they also have to be intelligently applied to the production of the materials they are intended to cover. There is no question that steel absolutely without any phosphorus in its composition would be most desirable, but so long as such metal is practically unattainable, why specify it? And knowing that the available iron ores of a country are best adapted to certain processes, it would seem unwise to expect its engineers to adopt specifications which would leave their own people out of the running.[9]

Thus, significant differences were emerging between the specifications of producing firms and the specifications of consuming firms. For example, the 1906 AASM specifications for steel rails stated that, if a test rail broke during the first drop test, two additional tests would be made; if these rails passed, then the entire lot of rails would be accepted.[10] As well, the AASM hoped to achieve agreement on using one grade of steel for all purposes.[11] By contrast, most consuming firms were opposed to retesting[12] and were beginning to consider using different grades and types of steel.

Steel producers began to change their attitude toward their customers' involvement in research into steel toward the end of the 1910s, but only slowly. By 1919, with the end of World War I, an Iron Age editorial noted the increased importance of the chemist to the steel

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[9]The Iron Age, June 26, 1913, p. 1570.

[10]Association of American Steel Manufacturers (AASM), Manufacturers' Steel Specifications, Rails, Pittsburgh: AASM, 1906, pp. 2-3.

[11]The Iron Age, April 30, 1903, p. 28.

[12]As Charles Dudley stated in 1907, "Multiple tests are pernicious and should be abandoned. Retests, including the sampling, should never be made unless there is reasonable evidence to think that there is an error in the first test. . . . Shipments of material once fairly rejected, should never be accepted and used if the material is of such a kind that safety or risk to human life is involved." See ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 35.

industry; the trade journal was only then beginning to downplay the role of the rule-of-thumb steelmaker and to laud the scientific steelmaker:

> Not many years ago the production of a heat of steel was simply a melting operation and little attention was paid to the chemical reactions involved. . . . Present-day practice demands more and more the educated chemist and metallurgist as the actual steel maker and not the man who was once the stocker and then the helper or melter.[13]

In short, during most of the first three decades of this century, steel producers relied on the innovative efforts of steel consumers in devising new steels.[14] Through the efforts of steel consuming firms in making and using specifications steel producing firms began to participate more actively in industrial research to improve steel in the 1920s. Steel consuming firms also worked through technical associations to improve steel. What follows is a description of how steel consumers successfully induced more industrial research by steel producers through an important and unique technical association, the American Society for Testing Materials (ASTM). The ASTM was established to resolve the ongoing dispute between producers and consumers over the appropriate terms for reasonable specifications, and as such, helped to redefine the meaning of ideal specifications:

> Under ideal specifications . . . it is conceivable that the producer might regard the rejection of material, not as a penalty, but rather as a protection in keeping from service improper material, failure of which would react on his business and reputation. The ideal specification is one

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[13]Editorial, The Iron Age, July 24, 1919, p. 250.

[14]See The Iron Age, March 6, 1930, p. 720.

which can be reliably met by a producer who is competent and willing.[15]

The ASTM was an organization that, by contrast to previous technical or industrial trade associations, was composed of representatives from both producing and consuming firms, and helped to resolve the disputes between these two groups regarding specifications and needed improvements in steel.

Section 2. The Origins of the American Society for Testing Materials

The International Association for Testing Materials (IATM), the predecessor association to the ASTM, was formed in 1898 to be an international society of engineers that would "bring together as many as possible of those interested in the subject of materials of engineering,"[16] with the objective being to "harmonize and standardize specifications for materials."[17] The first officers of the American section of the IATM included individuals prominent in steel metallurgy and industrial research: two academics, Mansfield Merriman, professor of civil engineering at Lehigh University and Henry Howe, professor of metallurgy at Columbia; and two industrial researchers, Richard Humphrey, engineer in charge of the testing laboratory at Philadelphia

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[15]ASTM, Proceedings, Philadelphia: ASTM, 1917, pp. 41-43.

[16]C. D. Young, "Condensed Information concerning the American Society for Testing Materials," Philadelphia: ASTM, 1916, p. 1.

[17]Young, "Condensed Information concerning the American Society for Testing Materials," p. 1.

and Paul Kreuzpointner, superintendent of the testing laboratory at the PRR.

The IATM's agenda was international in scope. It included some broad industrial research goals: establishing the scientific basis of existing specifications for metals; universalizing specifications; and standardizing nomenclature and methods of testing and inspection. Narrow theoretical studies were conducted as well--including studies of the magnetic and electric properties of steel, chemical and thermic properties of special steels, pig iron, resistance tests, and caoutchouc.[18]

One important aspect of the industrial research of the IATM and the later ASTM was its orientation toward commercial objectives. The American members of the IATM had commercial aims in mind, believing that standardization of products would lead to better industrial products and processes. One of the first studies of the American section of the IATM, conducted in 1899, reflected the American emphasis on commercial objectives: the study was a consideration of how standard specifications would lead to improved industrial methods and processes.[19] The first committees formed by the American section of the IATM were organized to address specific commercial interests of American industry: impact tests; open-hearth steel for bridges; Bessemer steel for rails; heat treatment for all industrial grades of iron and steel; and determination of the "relation between the chemical composition and the physical

[18]ASTM, Yearbook, Philadelphia: 1910, ASTM, pp. 12-13.

[19]American section, IATM, Bulletin No. 1, Philadelphia: American section, IATM, July 30, 1898.

properties of iron and steel, especially in connection with finishing temperature."[10]

Another important aspect of the research of the American section of the IATM and the later ASTM was its willingness to assist consuming firms in working with producing firms to develop specifications. In 1900 a group of New York bridge engineers contacted W. R. Webster of the IATM to inquire about specifications for bridge steel; because American steel producers hoped to increase exports through standardization of products, they were anxious to get standard specifications and conceded some disputed points to the engineers.[11] Steel producing firms seemed eager for assistance from consuming firms in these early days: in fact, a 1900 Iron Age editorial welcomed the assistance of steel consumers and technical associations in developing specifications for steel products, because "it will be a powerful incentive to a general adoption of the specifications if they escape the suspicion that the maker rather than the consumer was favored in framing them."[12]

A third important aspect of the industrial research of the IATM and the later ASTM was its cooperative nature. In fact, the American section of the IATM proposed broad-based cooperative efforts between consuming and producing firms from its inception. They solicited assistance from other national technical associations--the American

[10]American Section, IATM, History, Laws, Committees, and List of Members, Philadelphia: American Section, IATM, January, 1899, p. 19.

[11]The bridge engineers were especially concerned about the requisite strength and elastic limit of carbon steel. See The Iron Age, October 4, 1900, p. 10.

[12]The Iron Age, November 1, 1900, p. 26.

Society of Civil Engineers, the American Society of Mechanical Engineers, and the American Institute of Mining Engineers.[13] By 1900, the American membership of the IATM already included a cross-section of persons from both producing and consuming firms with interests in steel products.[14] In 1900 the American section of the IATM set out to devise its first specifications for various steel products being used in the U.S., including steel rails.[15] A sizable portion of this early work consisted of collecting "the best features of existing representative specifications, and no small work of the sub-committee was the collection and tabulation of existing American specifications;"[16] in the process, the testing methods of thirty-three steel producing firms were surveyed.[17]

In 1902, the American section of the IATM broke from the international group. There had been significant difficulty in forming standard specifications on an international basis.[18] Also, the American members were more interested in standardizing specifications for

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[13]The Iron Age, May 10, 1900, p. 20.

[14]The membership included seventeen representatives from steel producing firms, three representatives from railroads and four from other steel consuming firms, four representatives from consulting and testing firms, one city engineer, a representative from the Franklin Institute, and three professors. See The Iron Age, May 17, 1900, p. 12.

[15]Other products for which specifications were considered included: structural steel, boiler plate, rivet steel, steel splice bars, steel axles, steel tires, steel forgings, and steel castings. See The Iron Age, May 10, 1900, p. 20.

[16]The Iron Age, May 17, 1900, p. 12.

[17]The Iron Age, August 9, 1900, pp. 6-7.

[18]As one British engineer argued, universal international specifications for rails, for example, might well be impossible due to major differences in climates, processes, ores, and traffic patterns of various countries. See The Iron Age, July 25, 1907, p. 241.

commercial materials than in developing theories of testing--the latter being a central aim of the international membership by this time.[29] The American members believed their central concern was that

> . . . buyer and seller have greater difficulty in agreeing on the specifications which the material bought and sold must fulfill, than in agreeing on the methods to be used for deciding whether those specifications, once agreed on, are fulfilled by a given lot of material.[30]

In 1902, the American section of the IATM incorporated as a separate and autonomous group--the American Society for Testing Materials, and dedicated itself to "the promotion of knowledge of the materials of engineering, and the standardization of specifications and the methods of testing."[31] Membership in the ASTM grew steadily over the next three decades, with both producing and consuming firms joining in large numbers.[32]

The goals of the newly incorporated American society were explicitly commercial: first, developing tests and specifications for materials of importance to American industry and second, designing specifications on which buyers and sellers could agree. These goals were determined at a conference of the ASTM's early leaders--a broad cross-section of steel producers, steel consumers, and independent

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[29]ASTM, <u>Proceedings</u>, Philadelphia: ASTM, 1906, p. 24.

[30]ASTM, <u>Proceedings</u>, Philadelphia: ASTM, 1902, p. 17.

[31]ASTM, <u>Yearbook</u>, Philadelphia: ASTM, 1910, p. 8.

[32]Membership increased steadily over the next three decades, from 175 persons in 1902, to 600 persons in 1905, to 2100 by 1916, 2500 by 1919, and 4200 by 1928. See ASTM, <u>Proceedings</u>, Philadelphia: ASTM, 1904, p. 572; C. D. Young, "Condensed Information Concerning the American Society for Testing Materials;" <u>The Iron Age</u>, June 26, 1919, p. 1748; and <u>The Iron Age</u>, July 5, 1928, p. 28.

experts including: steel consuming firms like the Pennsylvania Railroad, the Philadelphia and Reading Railroad and the American Bridge Company; steel producing firms like Pennsylvania Steel, Carnegie Steel, Lukens Steel, Monongahela Steel, Cambria Steel and Illinois Steel; and independent experts like Henry Howe of Columbia, Edgar Marburg of the University of Pennsylvania, and Lesley, Webster, and Humphrey, consulting engineers.[33]

The early membership ranks of the ASTM reflected the four groups most active in promoting the new association: steel producing firms, railroads, independent testing firms, and university engineering and chemistry professors.[34] In short,

> . . . the balance has been quite well preserved between manufacturers or engineers representing them, and consumers or engineers representing them. In addition to these two interests, there is a neutral body of engineers connected with technical schools, whose investigations are carried on with a view to adding to the sum of scientific information on materials of construction. These tend to preserve the balance between interests sometimes conflicting.[35]

The importance of the ASTM was in the way in which it brought together, in a formal organization, producing and consuming firms so they could discuss and agree on the desired chemical and physical

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[33]The Iron Age, June 16, 1902, p. 8.

[34]Of 168 members in 1901, 37 represented steel producing firms; 13 represented railroads; 39 represented independent testing firms; and 34 were university professors. See American Section, IATM, Proceedings, Philadelphia: ASTM, 1902. By 1903, total membership had increased to 431, with 79 representatives from steel producing firms, 64 academics, 44 railroad representatives--nine of these from the PRR alone, and 79 representatives from independent testing firms. See ASTM, Proceedings, Philadelphia: ASTM, 1903.

[35]The Iron Age, July 6, 1905, p. 13.

characteristics in specifications for materials. Thus the very foundation of the ASTM was cooperative backward-linked industrial research:

> . . . we help maker and buyer to agree . . . . We do our share of the great work of the twentieth century, the substitution of cooperation for combat. By helping both parties to see both sides of the question, to see the true needs of the public, which, in the end, we all serve, we help both parties to approach and at last to attain the attitude of cooperation in striving toward their common true interest, to serve that public the best.[34]

When, in 1904, the Executive Committee of the ASTM reported on its progress to date in devising specifications for steel products, it could point to cooperation from various other technical associations--the American Society of Civil Engineers (ASCE) had assisted with making specifications for structural steel and steel rails; the American Society of Mechanical Engineers (ASME) had assisted with making specifications for boiler plate, rivet steel, steel forgings, and steel castings; the American Master Mechanics Association (AMMA) had assisted with making specifications for bridge materials and steel rails; and the American Institute of Mining Engineers (AIME) had assisted with making specifications for steel rails, forgings, and castings. Interestingly enough, there was little difference in the chemical specifications issued by the AASM, the ASTM, and the ARWEMW. The ASTM Executive Committee saw great value in securing cooperation from other technical associations:

> . . . the desirability of arriving at some uniform basis of reasonableness in specifications governing iron and steel is too obvious for extended argument. The ordering of material . . . which is to be subjected to similar or identical conditions of service under a great multiplicity of specifications, differing often more in the letter than in the

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[34]ASTM, Proceedings, Philadelphia: ASTM, 1911, p. 23.

spirit, is harassing to the manufacturer and of no real advantage to the consumer. . . .

The existing differences between the leading specifications framed within recent years are in the main on matters of minor importance, and what has been done has resulted in a considerable clearing of the atmosphere. . . . If the task be approached in a fair and reasonable spirit of compromise between interests whose divergence, broadly viewed, is more apparent than real, all parties will be the gainers.[37]

The ASTM established various standing committees to investigate specific products or processes. The ASTM performed its industrial research work through these various standing committees in the laboratories of member firms. Thus the ASTM was able to conduct industrial research fairly inexpensively and to disseminate industrial research results fairly rapidly to representatives of both consuming and producing firms.[38]

Membership on ASTM technical committees typically included the producing and consuming firms most directly involved in producing or

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[37]"The Standardization of Specifications for Iron and Steel," The Iron Age, February 25, 1904, p. 36.

[38]The Iron Age, July 6, 1916, p. 24. The following example is illustrative of the lengths to which the ASTM went to establish members' abilities to participate in the research work of the committee. McClaren Rubber Company, which became an elected member of the ASTM only in 1920, applied for membership on the ASTM Committee D-11 on Rubber Products. Before being accepted for membership, they were first requested by the committee to report on their research facilities. McClaren's chief chemist Charles Miller reported that McClaren's laboratories included both an experimental rubber mill and a rubber calender, complete with vulcanizer and press, as well as a Scott horizontal testing machine for physical tests of rubber specimens and chemical testing facilities. He observed, however, that "we will not be able in the next six months to devote very much time to committee work, but our idea is that in the future the Company will be willing and able to do their full share of work on either of these committees." See Charles G. Miller to C. L. Warwick, February 3, 1920, Box 673, PRR File.

using the relevant products.[39] This kind of interaction between producers and consumers in making specifications originated with the PRR in the 1880s and was carried to the ASTM by its first president, Charles Dudley (See Chapter 3, above). Producing and consuming firms worked together on ASTM committees to carry out research projects intended to make specifications or to investigate questions of commercial interest. Thus producers and consumers of commercial engineering materials were brought together, to discuss, and eventually, to achieve consensus, regarding the appropriate qualities for these materials. The balance of interests was a crucial part of the ASTM committee structure:

> . . . on committees dealing with subjects having a commercial bearing, either an equal numeric balance is maintained between the representatives of consuming and producing interests, or the former are allowed to predominate with the acquiescence of the latter. Unattached experts are classed as representatives of consuming interests.[40]

To preserve consumers' interests, technical committees were typically chaired by a non-producer.[41] Edgar Marburg, professor at the University of Pennsylvania and a charter ASTM member, saw the ASTM committee structure as benefitting producers and consumers by producing a

> . . . spirit of reasonable cooperation between both parties [for] . . . standard specifications . . . now being evolved by our leading committees, and it is for reasons just stated [unanimous endorsement for specifications on the part of the committee] that the producers are not disposed [sic] to

[39] The Iron Age, July 16, 1916, p. 24.

[40] Young, "Condensed Information concerning the American Society for Testing Materials," p. 3.

[41] ASTM, Proceedings, Philadelphia: ASTM, 1914, p. 640.

being so largely outnumbered on certain committees by the consumer.[42]

The committee structure also helped to focus the efforts of producing and consuming firms on specific commercial products. As A. A. Stevenson recalled in 1917,

> as the Society grew in numbers and the field of its work broadened, it would have been impossible for the body as a whole to have given the same time to the detailed discussion of individual specifications as in the early days. That situation was therefore met by throwing more responsibility upon the committees.[43]

Despite the institutionalized cooperation, there were frequent disputes between the two groups. As Mansfield Merriman, an independent consulting engineer and ASTM member, reminisced in 1915, there was, early on, some difficulty with consuming firms having majority representation on committees: consuming firms were apt to ask for tests and procedures that were not yet technologically feasible and overlooked the difficulties for producing firms in devising testing methods "that shall be rapid and cheap as well as precise."[44] Yet Stevenson, a long-time member of the steel committee, observed that committee work helped to lessen such contentious feelings between producers and consumers and eventually yielded fruitful results:

> In the early years, when a specification was proposed the first step would be to tabulate all the important existing specifications and then to build up from such tabulations. When that stage was reached, the struggle began between the consumers on one side and the producers on the other, the consumers making every effort to get as much as

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[42]ASTM, Proceedings, 1914, p. 647.

[43]ASTM, Proceedings, Philadelphia: ASTM, 1917, p. 41.

[44]ASTM, Proceedings, Philadelphia: ASTM, 1915, p. 37.

> possible; the producers to yield as little as possible. Both parties had certain reasons for their action, the consumer feeling that the producers were unreasonable, the producers feeling that no matter what was conceded some of the consumers would afterwards try to force further concessions in drawing their own specifications. That this feeling of antagonism has largely disappeared should be a source of great encouragement in looking towards the future. Both consumers and producers are realizing more and more that their interests are really mutual and the combined effort now is to endeavor to determine the facts and to use these facts as a basis for their work. . . .[15]

ASTM committees were responsible for devising the substance of proposed specifications, which were then voted upon by the collective body of the ASTM at its annual meetings. Two-thirds of the members present had to approve a proposed specification in order for it to be made an official ASTM specification. C. D. Young, chair of the steel committee for many years and head of the PRR test department, believed that, through this consultative and deliberative process, consuming and producing firms came to agree on the provisions in the specifications:

> any work offered for acceptance as a standard cannot be ultimately adopted until all of the interests involved in the problem have adjusted their ideas to the common standard.[16]

This interactive and iterative process made specifications more readily accepted and used by both producers and consumers.

As with the PRR, most of the early attention of the ASTM was directed toward steel products. Of eighteen committees in 1904, six dealt with iron and steel products;[17] of eighteen standard specifications

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[15]ASTM, Proceedings, Philadelphia: ASTM, 1917, pp. 41-43.

[16]Young, "Condensed Information concerning the American Society for Testing Materials," p. 4.

[17]ASTM, Proceedings, Philadelphia: ASTM, 1904, p. 572.

adopted by the ASTM by 1906, seventeen concerned iron or steel products.[48] One of the most important committees, and the first committee established by the ASTM, was committee A-1 on Standard Specifications for Steel. Various sub-committees were later established to deal with specific steel products and to conduct special investigations into corrosion or heat-treated steel. The 1910 steel committee membership included both prominent steel consuming and steel producing firms: of the committee's forty members, seventeen represented steel producing firms, six represented steel consuming firms, and seventeen represented independent testing firms (who, according to ASTM regulations, were classed with the users' representatives).[49] The ASTM thus was able to use its institutional framework to facilitate communication by steel consumers regarding the desired properties in steel, and by steel producers regarding the technical and pecuniary difficulties of these desired improvements.

Bringing together competing interests in this fashion, in the view of at least two prominent early members of the ASTM, produced rapid and remarkable results. Charles Dudley observed that much improvement had come about in the area of preservative coatings for iron and steel, "greater than in many years proceeding,"[50] due to the

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[48]Specifications issued included those for structural steel for bridges, ships, and buildings; for open-hearth steel boiler plate and rivet steel; for steel rails; for steel splice bars; for steel axles and steel tires; for steel forgings and castings; for wrought and foundry pig iron; for cast iron pipe and car wheel; for locomotive cylinders; and for malleable and gray iron castings. See ASTM, Proceedings, Philadelphia: ASTM, 1906, p. 23.

[49]ASTM, Yearbook, Philadelphia: ASTM, 1901, pp. 235, 245.

[50]The Iron Age, July 6, 1905, p. 16.

balance of consuming and producing interests on ASTM committees which had "contributed greatly to thoroughness of investigation."[51] Robert Lesley of American Cement Company and vice-president of the ASTM claimed that "in the broad sense, their interests are not conflicting ones, and every step toward their better reconciliation will be of mutual advantage."[52]

In short, improving materials through standardizing specifications would help both consuming and producing interests. Other technical associations and government agencies increasingly looked to the ASTM for information on specifications and standards.[53] Improvement in product quality as it was promoted by the efforts of the ASTM will be illustrated by the story of the ASTM steel rail investigations.

Section 3. The ASTM Steel Rail Investigations

Steel rails were a major concern of the ASTM steel committee, and indeed, of many rail users and technical associations during the first two decades of this century (See Chapter 3 above). But, in contrast to the efforts of these other associations and firms, ASTM debates had an advantage in that they brought together steel producers and steel consumers on a regular basis. The substance of these debates mirrored the change in research into steel during the 1910s, from an emphasis on

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[51] The Iron Age, July 6, 1905, p. 16.

[52] ASTM, Proceedings, Philadelphia: ASTM, 1906, p. 23.

[53] Young, "Condensed Information concerning the American Society for Testing Materials," 1916.

identifying defects in steel products to an emphasis on devising new materials and processes to yield better quality rails. More importantly, they induced backward-linked research by steel producing firms into ways to improve rail steel.

Establishing desirable characteristics for quality steel rails and placing them in specifications was a major goal of the early ASTM. The first step was to examine the existing specifications; thus, at the 1904 meeting, William Webster presented the steel rail specifications recently adopted by the American Railway Engineering and Maintenance of Way Association[54] as the prototype specifications for steel rail consumers. Deliberations over proposed changes to the ASTM specifications began in earnest in 1905, with input from both producing and consuming firms. Yet the actions proposed by the ASTM steel committee were minor: the steel committee, in response to objections raised by steel producers, recommended that the drop test requirement be softened,[55] and, in response to consuming interests, recommended that the sampling procedure be made more rigid by requiring that test pieces be taken from the top of the ingot where most of the defective steel collected.[56]

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[54]The Iron Age, September 12, 1912, pp. 614-15.

[55]The proposal was to make the drop test on every fifth lot of steel rather than on every lot, thus reducing the probability of rejection based on the drop test.

[56]This differed from previous language that stated that test pieces should "'preferably'" be taken from the top. As steel consuming firms believed that most of the defects collected at the top of the ingot, this provision was believed to be a more certain way of detecting defects. See The Iron Age, July 6, 1905, p. 17.

But a heated debate between steel consuming and producing firms opened that year--a debate centering on steel quality. Steel consuming firms began to fault steel producing firms for faulty and careless manufacturing processes believed to cause the defects beginning to be found in rails, while steel producing firms began to fault steel consuming firms for making inadequate adjustments to their track and equipment to compensate for increased rail traffic.

The position of the railroads was stated most clearly by two prominent railroad representatives at the 1905 ASTM meeting: Robert Job, chemist for the Philadelphia & Reading Railroad, contended that there had been a deterioration in rail quality due to manufacturing defects. Charles Dudley argued that steel producers were making larger ingots so as to increase output but that these larger ingots were more likely to contain defective steel.[17] Steel rail consumers also presented research into failed steel rails, generally concluding that steel producing firms had directed their efforts at increasing steel output at the expense of steel quality. One of the earliest studies was conducted by Robert Job into rail failures on his railroad. He concluded that most of these had been caused by defective steel--defects such as pipes, blowholes, excessive segregation, or coarse granular structure were found upon analysis of the rails. Job concluded, in strong words:

> . . . to sum up, the results of our investigations indicate that the greater part of the difficulty which occurs to-day with rails under heavy traffic is due to unsound condition of the steel, a condition which existed in comparatively slight degree in the earlier rails . . . . unfortunately, in the essential element of soundness of the steel there has been direct retrogression, making it appear that the main

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[17] The Iron Age, July 6, 1905, p. 17.

> attention in the manufacture has been fixed upon quantity and not quality of the output.[58]

By contrast, steel producing firms argued that they had improved steel quality as well as quantity. Bostwick of Carnegie Steel contended that defective rails were perceived to be more numerous than they really were because rails were being scrutinized more carefully than in previous years.[59] Campbell and Carhart, representatives for steel producing firms, argued against making specifications more rigid: in their view, the ideal specification for rails

> . . . should be one meeting the general demands of commerce and not the most rigid that can be designed. The fact that each railroad had its own specification made refinements in a general specification unnecessary.[60]

Given the fundamental disagreement about the cause of rail failures, it was likely that there would be some difficulty in formulating a steel rail specification acceptable to both groups. A weak specification for steel rails was approved by the ASTM steel committee and presented to the entire ASTM in 1907; an important provision concerned the discard, a procedure that the railroads requested from producers to ensure removal of defective steel from ingots before rolling rails. The specification required, in vague language that signalled a compromise, that

> . . . there shall be sheared from the end of blooms formed from the top of the ingots not less than XX percent, and if, from any cause, the steel does not then appear to be solid, the shearing shall continue until it does, . . . [XX

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[58] ASTM, Proceedings, Philadelphia: ASTM, 1905, p. 163.

[59] The Iron Age, July 6, 1905, p. 17.

[60] The Iron Age, July 5, 1906, p. 17.

representing] the percentage of minimum discard in any case to be subject to agreement and it should be recognized that the higher this percentage the greater will be the cost.[61]

In 1907, the conflict had subsided somewhat. Iron Age reported that the expected "sharp passages"[62] between steel producers and railroads did not occur at the 1907 meeting: steel producing firms "for the most part confined themselves to correcting statements that did not tally with their experience and to emphasizing some particulars in which railroad practice was responsible for rail troubles."[63] Yet a considerable number of points continued to be disputed.

Many steel producing representatives defended the practices of their firms. For example, Carhart of Carnegie Steel argued that the increased output by steel producers came from use of more efficient practices and not from sacrifices in quality.[64] Steel producing representatives continued to blame the railroads for failed rails: William Webster argued that railroads had not adjusted rail weights in proportion to the increased rail traffic: "we are coming to heavier rails before we get rid of our present troubles. . . . it must be admitted that a fair percentage of breakages is caused by the great increase of wheel loads since 1892."[65] Similarly, Thackray of Cambria Steel declared that the railroads were using rails of insufficient weight:

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[61]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 39.

[62]The Iron Age, June 27, 1907, p. 1948.

[63]The Iron Age, June 27, 1907, p. 1948.

[64]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 113.

[65]ASTM, Proceedings, 1907, p. 89.

. . . in their desire for tonnage, for large and paying traffic, the railroads have increased the size and weight of cars, . . . while at the same time they have allowed the weight of their rails to lag behind . . . . [66]

The railroads insisted on higher quality steel as the remedy to rail failures. R. W. Hunt, an independent testing engineer, argued that, not railroad practices, but rather, the inferior quality of rail steel, was to blame:

heavier sections . . . will not do a bit of good, no matter what may be the design, unless the manufacturers will make it carefully and put good steel into it; and in my judgment, based on many years' experience, they cannot do that unless they take more time in the operations incident to the making than is now generally the case.[67]

In his view, the desire for increased output on the part of producing firms overran all other considerations.[68] P. H. Dudley, consulting engineer for the railroads, asserted that more systematic study of steel metallurgy was needed:

It was not carelessness, incompetence, nor dishonesty of the iron masters, as often alleged, but the fact that the work required of the metal exceeded its physical properties, and fatigue, failure, and fracture were the inevitable consequences after short service.[69]

Charles Dudley believed that rail failures resulted from inadequate technological adjustment on the part of steel producers: the

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[66] ASTM, Proceedings, 1907, p. 118.

[67] ASTM, Proceedings, 1907, p. 94.

[68] ". . . the skilled employees of a rail mill are paid by the ton . . . . therefore the danger exists that sometime the full running of the mill may be under what can be designated as a strained condition." See ASTM, Proceedings, 1907, p. 115.

[69] ASTM, Proceedings, 1907, p. 55.

. . . operations of the railroads due to the commercial demands and development of transportation in thirty years after their inception, outgrew the physical properties to be obtained in iron rail sections as a metallurgical product in forms of value as engineering structures.[70]

Churchill of the Norfolk and Western argued that more homogeneous steel material was required for rails. In summary, therefore, railroad representatives blamed rail failures on defective steel and careless mill practices.[71]

Another disagreement was over the railroads' willingness to pay for better rails. Steel producers typically argued that railroads were unwilling to pay higher prices to get better steel. The Norfolk and Western's Churchill contended that railroads would pay higher prices for rails if they could be guaranteed better steel:

> If the steel is homogeneous and good as we expect to get for the prices we pay, . . . then we would not have such breaks. . . . I do not believe there is a single railroad in the United States that would fail to meet the exact cost that the mills think necessary to produce improved material.[72]

Hunt argued that the required increases in costs ought to be identified and discussed openly:

> if producing higher quality rail steel would be more costly for steel producers, then they ought to state these costs and railroads ought to state if they would pay these costs.[73]

In short, there was no consensus between steel producers and consumers regarding the necessary improvements for rail steel in 1907.

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[70]ASTM, Proceedings, 1907, p. 55.

[71]ASTM, Proceedings, 1907, p. 74.

[72]ASTM, Proceedings, 1907, p. 111.

[73]ASTM, Proceedings, 1907, p. 111.

The steel committee's proposed rail specification did not receive ASTM approval. The ASTM decided to resolve the question by appointing a subcommittee to deal specifically with steel rails, selecting four steel rail producing representatives and three steel consuming representatives.[14] The committee was charged to study the proposed specification intensively before adoption and to iron out the differences between producing firms and railroad representatives.[15]

Resolution of the rail question became increasingly important to steel consuming interests within the ASTM. Dudley brought the rail question to the attention of the entire ASTM in his 1908 presidential address, noting the increase in rail breakages over the past three years.[16] Dudley was of course more sympathetic to the rail consuming interest, citing "careful studies"[17] that indicated that rails had been increased in weight more than sufficiently to cover the increased loads.[18] It was not as clear that steel producers had made similar efforts:

> . . . again and again [they] have washed their own hands entirely of responsibility in this matter, and claimed that it was simply a question for the inspectors and engineers. We have heard them say in effect, not once, but many times, 'our mills are open to you. Here are the rails. Take them

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[14]ASTM, Proceedings, 1907, p. 39. The members of this subcommittee included Bostwick and Carhart of Carnegie Steel, Kenney and Thackray of Cambria Steel, Dudley of the PRR, Marburg of the University of Pennsylvania, and Webster, an independent consulting engineer.

[15]The Iron Age, June 27, 1907, p. 1955.

[16]ASTM, Proceedings, Philadelphia: ASTM, 1908, pp. 19-20.

[17]ASTM, Proceedings, 1908, p. 22.

[18]ASTM, Proceedings, 1908, p. 22.

> or leave them;' thus practically putting the whole responsibility of accepting and using defective and inferior material upon those who from the nature of the case cannot know as well as the manufacturer, which are good and which are bad."[79]

In Dudley's view, steel had deteriorated in quality for several reasons: steel was now made in larger ingots, producing greater segregation in the steel; steel was processed more rapidly, causing incomplete chemical reactions; and steel was made with higher finishing temperatures, weakening the steel.[80] In his view, railroads had made considerable progress in their testing procedures, but would have to continue to improve the testing procedures that had been too loose in the past, "partly owing to inertia on the part of railroad engineers, and partly owing to the resistance of the rail manufacturers."[81] Many specifications had omitted critical details about the drop test--for example, the size of the anvil to be used or the support on which the rail was placed during the test.[82]

To solve the rail problem, three efforts were needed: more data on rail failures, more cooperation from steel producers, and more progress in rail specifications--and these efforts were all underway by the ASTM. Thus the ASTM would play a crucial role in inducing improvements in rail steel: it would stimulate dissemination of information on steel metallurgy; it would arouse interest in testing; and, most importantly, it

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[79]ASTM, Proceedings, 1908, p. 27.

[80]ASTM, Proceedings, 1908, p. 28: "Bessemer metal is, many times, cast in the ingot mold, before the reactions are complete."

[81]ASTM, Proceedings, 1908, p. 34.

[82]ASTM, Proceedings, 1908, p. 35.

would furnish a forum for consumers and producers to meet.[13] As Dudley commented, over the past two decades there had been

> . . . too much antagonism, far too much holding back essential information, and far too great a failure to cooperate. . . . in conferences over steel rail specifications, it has many times been simply impossible to get such information from the representatives of the steel makers, as would enable critical points in the specifications to be wisely decided. And this is not the worst of the matter. Within two years past, entirely reputable engineers of railroad companies have said in my presence that they had been told by rail manufacturers that if they did not take the rails offered, irrespective of specifications and tests, they would not get any . . . . it is only within the past year, or perhaps year and a half, that it has been possible to have what might be fairly called a consultation with the experts of the steel rail makers, over any point that involved the quality of the product, in any conciliatory, cooperating way.[14]

Accordingly, in 1908, the ASTM accelerated its investigations into steel rails and, in keeping with its stated objectives, served as a forum where detailed technical papers concerning steel rail technology could be presented to the diverse groups interested in steel rail improvement: steel producers, railroads, independent testing engineers, and academic researchers. In this way new technological information about steel rails was rapidly and systematically disseminated to all interested parties. Two papers presented that year reflected the increasingly technical scrutiny of failed rails: a microscopic investigation of broken steel rails was reported by Professor Fay at MIT that offered some evidence for chemical causes of defects in rails,[15] and a study of segregation-caused

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[13]ASTM, Proceedings, 1908, pp. 35-39.

[14]ASTM, Proceedings, 1908, p. 27.

[15]ASTM, Proceedings, 1908, pp. 74-93.

defects in steel rails was presented by Wickhorst of the Chicago, Burlington, and Quincy Railroad.[16]

In keeping with the ASTM's intent to provide a forum for cooperation and exchange of views, producers and consumers were able to respond publicly to these technical papers. Accordingly, Kenney of Cambria Steel raised the following conciliatory points:

> the users are beginning to admit that the trouble is not all in the rail, . . . and the makers are quite willing to admit that there are limitations in the art of steel making as known to-day.[17]

At the same time, Kenney also made a pitch for steel-producing firms: rail sections should be made larger and heavier; changes in section design should be made; new methods to test for piping and segregation should be developed and substituted for the discard procedure to avoid waste of steel; and the drop test should be eliminated because it

> so far exceeds any possible shock due to service conditions that it is unnecessarily severe and we must reduce it to avoid the rejection of any steel hard enough to give us the wear in the track that we should get.[18]

Kenney agreed with Dudley that more information was needed, and this was in the works: "taking the field as a whole, the indications are that we are in a fair way to get what in this subject in particular is badly needed, namely evidence."[19]

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[16]ASTM, Proceedings, 1908, pp. 94-98.

[17]ASTM, Proceedings, 1908, p. 99.

[18]ASTM, Proceedings, 1908, p. 106.

[19]ASTM, Proceedings, 1908, p. 108.

By contrast to Kenney, when Iron Age reviewed the ASTM meeting that year, it blamed the railroads and staunchly defended steel producers:

> . . . in every form of service in construction steel is being called upon to carry greater loads, sustain higher pressure, resist stronger attacks by corroding attacks . . . . It is certain they must be met by new methods, by greater care in the processes of manufacture, by the application of the discoveries constantly being made as to the effects of heat treatment and the alloying elements. We do not find that steel manufacturers have ever been satisfied to stop improving their product . . . . The question may properly be raised, however, whether the practice of the consumers of steel has improved as much as that of the steel mills.[11]

By 1909, Iron Age turned around and began to praise the ASTM debates as an effective means of resolving the dispute:

> the society's work has at times drawn sharp lines between opposing interests. The debates over steel rail specifications are a case in point. But this diversity of interest has proved an effective clarifier and has given the shortest cut to results. Now that the steel companies and the railroads have come to a better understanding, rail questions develop less heat . . . .[11]

Although the debate appeared to be subsiding, during the 1909 ASTM meeting a discussion about a minor technical detail in steel rails that was believed to cause various defects[11] induced another heated debate between steel producers and consumers. Steel producers characterized the increasingly technical investigations by railroad and testing engineers as being excessive, and went so far as to say that, for example, microscopic investigations of steel would generally "disclose

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[11]The Iron Age, July 9, 1908, p. 116.

[11]The Iron Age, July 8, 1909, p. 96.

[11]The technical detail was the presence of manganese sulphide, believed to be responsible for a large number of defects in rails. See The Iron Age, July 8, 1909, p. 100.

the thing for which the investigator is hunting."[13] Charles Dudley responded that these investigations were providing the badly needed data on rail defects:

> Is it worth while to make better steel? I answer as follows: If it costs more to make better rails than to give poorer rails such support in the track that they will not break under the conditions of service, it is not worth while to make better rails. On the other hand, if a better rail will diminish the cost of maintaining the track, more than the increase in the cost of the rail, better rails are certainly an absolute desideratum. Unfortunately we do not yet know where the true economy lies. It is hoped that the data which is now being obtained from rails in service, will enable this problem to be solved.[14]

Technical studies presented in 1909 continued to blame steel manufacturing processes for bad rails. Professors Fay and Wint of MIT analyzed the dangerous effects of slag in steel rails and recommended changes in steel manufacturing processes.[15] Two consulting engineers for the railroads, Robert Job and P. H. Dudley, argued that there was need for more investigation of the role of segregated steel in failed steel rails.[16] Fay observed that research by steel producers was conspicuously absent from these presentations:

> . . . the steel manufacturer has examined neither good nor bad material. If the steel manufacturer himself would help

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[13]The Iron Age, July 8, 1909, p. 96.

[14]ASTM, Proceedings, Philadelphia: ASTM, 1909, p. 109.

[15]ASTM, Proceedings, 1909, pp. 77-89. Their specific recommendations included: lower sulphur content, changes in pouring the molten metal into the ingot mold by producers of steel, and more attention be given to electric refining.

[16]ASTM, Proceedings, 1909, pp. 90-105.

> us along these lines, I think it would be much better than to simply play the role of critic.[97]

As the debate could not yet be resolved based on the evidence, there was little for the ASTM to do but continue to encourage more investigations of failed rail steel. Few changes could be made to specifications until more evidence was gathered and agreement was reached: even Iron Age reported in 1912, the proposed specifications for steel rails still "did not cover the rail question."[98]

By the early 1910s, steel producers became more active in research: Professor Webster, chair of the steel committee, noted that "good hands [were] now grappling with the problem."[99] Professor Howe agreed that it was the duty of the ASTM to promote systematic investigation of steel rail metallurgy in order to move beyond speculation and accusation:

> It is idle to plead that the fault lies primarily elsewhere . . . . The question then seems to resolve itself into these. First, is there a considerable number of rail breakages capable of prevention by means of better specification? Second, can we contribute directly or indirectly toward bettering those specifications by directing attention to their present defects?[100]

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[97] ASTM, Proceedings, 1909, p. 106. In defense of the steel producers, Howe, professor at Columbia and longtime affiliated with Taylor-Wharton, argued that "the practical steel manufacturers may have made more examinations than Mr. Fay is aware of."

[98] The Iron Age, April 4, 1912, p. 846.

[99] The Iron Age, April 4, 1912, p. 846.

[100] ASTM, Proceedings, Philadelphia: ASTM, 1912, p. 27.

In his view, one problem was that test conditions for materials were still far removed from actual service conditions.[101]

By the mid 1910s, the debate between consuming and producing firms became more constructive, due to increased involvement by steel producing firms in research. A 1914 Iron Age editorial reported progress on the rail problem due to increased cooperation between consumers and producers.[102] The AREA's Wickhorst presented research on steel rails to the ASTM in 1913 and noted increased participation by rail manufacturers in his investigation.[103] P. H. Dudley of the New York Central reported how steel producers had cooperated with his railroad in a study of rail steel ductility, and in particular, how Illinois Steel had rolled special ingots: in conciliatory fashion, he observed that future specifications should be formulated in such a way as to elicit the cooperation of the manufacturer.[104]

Despite this increased cooperation by steel producers, railroad representatives continued to argue for changes in manufacturing methods to eliminate defective rails.[105] Wickhorst called for steel treatments to reduce segregation and eliminate defects. A. L. Johnson complained that

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[101]ASTM, Proceedings, Philadelphia: ASTM, 1911, p. 24.

[102]The Iron Age, March 12, 1914, p. 680.

[103]ASTM, Proceedings, Philadelphia: ASTM, 1913, p. 582.

[104]The Iron Age, February 27, 1913, p. 539.

[105]The Iron Age, February 27, 1913, p. 590. However, he made the significant observation that "failures are confined to what may be called defective rails, and . . . most rails stand up to the service."

> specifications have not dealt with the finishing temperature, which is higher to-day in all rolled products than ever before, and is, in the writer's opinion, much higher than should be permitted, where quality in the output is required.[106]

Job's study of transverse fissures concluded that faulty steel manufacturing was to blame and he issued a laundry list of faulty manufacturing practices:

> if we eliminate from mill practice defective cropping, injurious segregation, strains of manufacture, either mechanical or due to irregular heat treatment, we rarely, if ever, find one of these fissures in a rail.[107]

The PRR's Gibbs, president of the ASTM in 1915, told the assembled members that the problem of defective steel rails had still not been solved: "that the real answer to this great problem has not been reached is proved by the continued unrest in our specifications, and by the everlasting changes in sections."[108] In his view, important technical problems with steel rails had been ignored by both sides. The ASTM specifications for steel rails were modified four times between 1907 and 1915 to conform to the AREA specifications, which produced a degree of standardization; however, there were some disturbing trends in these specifications. One unfortunate trend was that the ASTM continued to ignore the diversity of testing methods used to test rails and the substantial differences in test results obtained from these

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[106]ASTM, Proceedings, Philadelphia: ASTM, 1913, p. 172.

[107]ASTM, Proceedings, Philadelphia: ASTM, 1914, pp. 89.

[108]ASTM, Proceedings, Philadelphia: ASTM, 1915, p. 34.

different methods.[109] Another worrisome trend was making additional tests when an initial test piece failed--a dangerous and costly practice:

> The total additional cost per ton for eliminating both of these objectionable physical clauses is quite well known and is not large . . . . we hold that a buyer should not have to pay an additional price to avoid taking material which does not fairly meet the prescribed tests.[110]

Gibbs suggested a two-pronged approach to improving steel rails which would require cooperation from both railroads and rail producers: improvements in rail design and track inspection on the part of railroads, and more uniform steel on the part of rail producers.[111] Cooperative industrial research would be required:

> It is not to be expected that a mill will be willing to make changes in its practice until after experimental work has demonstrated that the proposed practice is practicable and valuable. This does not mean that the mere assertion that the changes are impracticable absolves us from doing anything further; on the contrary, the steel mills should be willing to go as far as possible in the direction of proving or disproving these theories.[112]

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[109]ASTM, Proceedings, 1915, p. 35. For example, neither AREA nor ASTM specifications addressed the considerable differences between the chemistry of the finished steel in the rails and the chemistry of the ladle analysis. Yet PRR analyses had shown substantial discrepancies in the results of these two forms of chemical analysis, and for that reason, PRR specifications had always detailed not only the requisite chemical composition but also the methods to be used to determine these chemical tests.

[110]ASTM, Proceedings, 1915, p. 37. As Gibbs noted, "any deviation from the beaten path is immediately met by an increase in the price asked, the reasonableness of which the purchaser has no means of determining. In at least one case of which I have knowledge, the actual expense of every kind . . . due to rail breakage on a certain system was less than one-fifth of the annual increase in the cost of rail due to the introduction of a proposed new specification designed to secure the quality of rail desired."

[111]ASTM, Proceedings, 1915, p. 35.

[112]ASTM, Proceedings, 1915, p. 40.

By the mid-1910s, cooperative industrial research efforts under the auspices of the ASTM began to emerge. Although there were as yet no precise answers to the rail question, the ASTM rail sub-committee was bringing about increased cooperation between rail producers and railroads as well as between the ASTM and other technical associations:

> in general the research being done upon rail steel is being carried forward in such a manner as to justify hope for the future. Both manufacturers and consumers are active in endeavoring to improve the quality of the steel in order to eliminate the failures, and are working out the problem in thorough cooperation.[113]

By 1916 considerable industrial research into rail steel was being done by ASTM steel committee members, some of these in connection with ongoing investigations by the AREA, the PRR, and other prominent steel consuming interests. The ASTM steel rail sub-committee, in cooperation with the AREA, concluded that split or crushed rails were caused by segregation in the steel; however, chemical tests were now available to detect segregation.[114] Transverse fissure failures were still not clearly understood by the ASTM steel rail committee; yet the rail sub-committee stated that "both manufacturers and consumers are active in endeavoring to improve the quality of the steel in order to eliminate

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[113]ASTM, Proceedings, Philadelphia: ASTM, 1916, p. 94.

[114]Chemical analysis could be used to identify the extent of segregation, although "the facilities which have been found necessary by the large railroad (the PRR) which has used this method are probably beyond the reach of many smaller railroads." This was the most reliable method of detection found to date. A second proposed method--estimation of the extent of segregation using Brinell hardness tests--had not yet shown practical results. See The Iron Age, July 6, 1916, p. 25.

these failures, and are working out the problem in thorough cooperation."[115]

1917 brought a greater degree of cooperative effort to resolve the dispute over defective rails. The ASTM steel rail sub-committee announced that it would undertake a joint study of stresses in steel rails with the ASCE and AREA.[116] As well, much information was being shared. PRR representatives shared their investigations into the quick bend test[117] and segregation in steel rails.[118] Burrows of the Bureau of Standards shared information on a magnetic method of testing rails for defects developed at the Bureau.[119] An AREA report on transverse fissures was presented as evidence that "induced interior transverse fissures can only develop in the track from the effects of preceding causes in the manufacture of rails."[120]

The increased cooperation signalled that ASTM rail investigations had moved forward, from a process of identifying and wrangling over causes of defects, to a process of working together to develop and implement more scientific testing techniques and better manufacturing

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[115] The Iron Age, July 6, 1916, p. 25.

[116] ASTM, Proceedings, 1917, p. 113.

[117] The Iron Age, July 5, 1917, p. 11.

[118] ASTM, Proceedings, Philadelphia: ASTM, 1917, p. 113.

[119] ASTM, Proceedings, 1917, pp. 111-12. This was a method however which was not yet perfected. Howard of the Bureau of Standards reported on the Bureau's efforts and stated the "necessity of acquiring more information upon the successive stages through which the metal in a rail passes from the time of fabrication until rupture is reached."

[120] ASTM, Proceedings, 1917, p. 112. This report was prepared by P. H. Dudley.

processes. Steel producing firms were cooperating more completely with railroads and were becoming more interested in rail steel metallurgy. By the end of the decade the ASTM had brought about considerable cooperation between rail producing and consuming firms on an important and controversial steel problem--defective rails, and were ready to move on to more challenging tasks in the line of industrial research.

Section 4. Cooperative Research with Other Technical Associations

An important aspect of the ASTM's efforts to stimulate cooperative industrial research in the U.S. was its active collaboration with other major technical associations. The ASTM's potential contributions in this area were recognized from the start, and were viewed by its leaders as a means of promoting the ASTM's importance within the emerging industrial research community and as a means of achieving usable research results: as Robert Lesley, ASTM vice-president, observed:

> . . . no steps in the preparation of specifications and the adoption of methods for manipulation of tests are proposed in any of the scientific societies to-day without the suggestion of the cooperation in the same by this body . . . . It is this cooperation which has tended to make our Society recognized as one of the leading ones in the United States, and one most devoted to work and most fruitful in results.[111]

Active cooperation remained a somewhat elusive goal throughout the 1900s when the ASTM was building up its own membership ranks and establishing its own research agenda. In 1902, the ASTM did propose to revise its specifications to make them conform more closely to

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[111]ASTM, Proceedings, Philadelphia: ASTM, 1906, p. 28.

the specifications of other technical associations: "The proper attitude for the Society . . . is . . . to give full and fair consideration to what has been formally proposed by other societies."[122] During the remainder of the decade, prominent metallurgists worked to persuade the ASTM to take a more active role in resolving controversies between producers and consumers regarding steel products and processes. In 1907 James Howard of the government's Watertown Arsenal requested cooperation from rail producers and railroads in an investigation of steel rails, and especially asked for the ASTM's assistance.[123] In 1911 Professor Henry Howe proposed that the ASTM could foster more rapid improvement of steel rails, and even eliminate rail failures, by cooperating more fully with the other technical associations and government agencies looking at the rail problem.[124]

It was not until the later 1910s that the ASTM began to engage more actively in cooperative efforts with other technical associations. In 1917, the ASTM organized a cooperative effort with four other technical associations, to work toward improving and standardizing specifications, an important step toward closer cooperation:

> [A] committee which is trying to evolve some plan of closer cooperation whereby standards may be made rational . . . . has made a report to the governing boards of the five societies of an American Engineering Standards Committee. The object of this committee would be to unify and simplify the methods of arriving at engineering standards, to insure

[122]ASTM, Proceedings, Philadelphia: ASTM, 1904, p. 38.

[123]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 109.

[124]The Iron Age, April 4, 1912, p. 846.

cooperation between the different societies and to prevent duplication of work.[115]

As well, during the 1910s, the ASTM began to receive wider recognition for its own research efforts and its efforts to organize collaborative research projects; as A. W. Gibbs, who had recently served as ASTM president, remarked, other technical associations were becoming more interested in the ASTM's work: "everywhere I go I see and hear less of the old suspicion that this Society was being run by certain interests, and more recognition of the fact that it is a broad engineering society."[116] In 1917, the AREA met in close proximity to the ASTM to demonstrate its growing interest in the ASTM's work.[117]

Collaborative research efforts proliferated as the American war effort wound down. In 1918 the ASTM sponsored a session on cooperative research in hopes of "render[ing] a worthy national service in the field with which it has long been prominently identified."[118] This 1918 conference sparked a dramatic increase in cooperative research efforts during 1919, with many formal links established between the ASTM and other technical associations. The ASTM appointed three of its past presidents to a national committee that was organized to

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[115]ASTM, Proceedings, Philadelphia: ASTM, 1917, p. 47.

[116]ASTM, Proceedings, 1917, p. 51.

[117]ASTM, Proceedings, 1917, p. 51.

[118]ASTM, Proceedings, Part 2, Philadelphia: ASTM, 1918, pp. 5-6. As John Johnston, head of the National Research Council and organizer of the conference observed, one of the "most striking consequences of the war is the increasing general realization of the primary importance of scientific research to the whole question of national defense, as well as to the successful prosecution of industry and the greatest measure of economy of resources after the war."

consider standardizing specifications, and selected representatives to the National Research Council, the Engineering Council, and the American Bureau of Welding.[129] The ASTM also initiated several national research committees of their own: cooperative efforts with the American Foundrymen's Association and the Steel Founders' Society to standardize steel castings, and with the SAE to develop specifications for aircraft steels, were launched; and cooperative efforts with the AREA to revise specifications for carbon steel rails were continued.[130]

One major cooperative effort began in 1918 due to the war's effects on steel supply. A heated debate erupted at the ASTM's annual meeting concerning a proposal to temporarily relax the requirements for sulphur and phosphorus content in many ASTM specifications. Most steel producers favored the proposal because they could not achieve the low levels of phosphorus and sulphur required by ASTM specifications under the current war conditions; although a few producers objected: for example, A. A. Stevenson of Standard Steel Works argued that such a move would "reflect on the welfare of the society."[131] Nonetheless, as Iron Age noted, the ASTM voted to accommodate producers by relaxing its specifications, in what was termed an unusual turn of events:

> . . . it resulted in the [steel] committee's being obliged to bring to the floor of the convention the particular specifications on which its vote was equally divided and on

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[129]The Iron Age, June 26, 1919, p. 1748. The Engineering Council was a new national society which aimed to establish a research committee to be located in Washington, D. C.

[130]The Iron Age, June 26, 1919, p. 1748.

[131]The Iron Age, July 4, 1918, p. 24.

> which the chairman would neither cast a deciding vote nor make a recommendation. Such a necessity is a very unusual procedure.[132]

Although the temporary relaxations were approved, the ASTM continued to struggle with these changes to its specifications during 1919; by 1920, it decided that more reliable information on the effects of sulphur and phosphorus was needed. The ASTM, the U. S. Railroad Administration, and the Bureau of Standards launched a joint investigation into the effects of phosphorus and sulphur on steel:[133] an important cooperative research effort for the ASTM:

> . . . this important metallurgical problem has received heretofore considerable attention in individual research laboratories but the present movement represents the first concerted effort of interested organizations to make a thorough study of it, and to combine their resources in a way to give impetus to a research problem of considerable magnitude.[134]

Cooperative industrial research efforts continued throughout the 1920s and were directed at an increasing variety of steel products and processes. At the 1921 meeting a cooperative effort was organized between the SAE, the American Society for Steel Treating, and the

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[132]The Iron Age, July 4, 1918, p. 14.

[133]Personnel of the committee included: G. K. Burgess and H. L. Whittemore representing the Bureau of Standards; F. M. Waring, PRR and H. E. Smith representing the Railroad Administration; Robert Hunt and T. D. Lynch of Westinghouse representing the ASTM; F. P. Gilligan of Henry Souther Engineering representing the SAE; E. F. Kenney of Midvale and J. J. Shuman of Jones & Laughlin representing the AASM; J. E. McCauley of Birdsboro Steel representing the Steel Founders' Society; F. C. Langenberg of the Watertown Arsenal and D. J. McAdam representing the nation's defense departments; Frank Gentles representing the U. S. Shipping Board; and John H. Hall of Taylor-Wharton representing the National Research Council.

[134]The Iron Age, February 5, 1920, p. 397. In 1921 this study was placed under the Bureau of Standards, with the agreement of the ASTM. See The Iron Age, June 30, 1921, p. 1759.

National Research Council to study heat treatment.[135] In 1922 the ASTM steel committee reported on its joint research with the American Railroad Association on annealed cast steel for railroads,[136] a cooperative effort marked by considerable dialogue between steel producers and railroads.[137] In 1923 the Association of American Steel Manufacturers requested the assistance of the ASTM, the American Petroleum Institute and petroleum companies, to study the specifications for steel products used by the petroleum industry.[138] In 1924 the ASTM formed a joint committee with the ASME to examine the effect of temperature on the properties of metals:[139] this particular study signalled that there was a new era of cooperation between steel producing and consuming firms, because all producing and consuming firms that were contacted agreed to cooperate; and many had already equipped themselves to handle high-temperature tests of steel.[140] In 1925 the ASTM formed a joint

[135]The Iron Age, June 23, 1921, p. 1702.

[136]The members of the committee included representatives from Pratt & Letchworth Company, Ohio Steel Casting Company, Birdsboro Steel Foundry Company, and Union Steel Casting Company, the latter which performed tests on steel castings. The majority of the committee's efforts were devoted to the question of yield point and elastic limit. See The Iron Age, July 6, 1922, p. 13.

[137]Although the committee did adopt tentative specifications for cast steel, Fry of Standard Steel Works noted that the commercial method for testing the elastic limit of steel was less precise than other tests used experimentally. Comstock of Titanium Alloy Manufacturing Company argued that the test results were not 'scientific' due to the lack of using an extensometer. The committee's work and results were defended by Professor H. F. Moore of the University of Illinois. See The Iron Age, July 6, 1922, p. 13.

[138]The Iron Age, June 28, 1923, p. 1861.

[139]ASTM, Proceedings, Philadelphia: ASTM, 1925, p. 505.

[140]The Iron Age, November 5, 1925, p. 1259.

committee with the American Society for Steel Treating and the SAE to study heat-treatment of steel and to agree on definitions of heat-treated steel.[141]

By the late 1920s, the cooperative research efforts under the aegis of the ASTM began to attack more specific questions. In 1928 the ASTM and the ASME initiated its second study of fatigue and thermal conductivity of metals at high temperatures;[142] by 1930 this joint research committee moved into a third study that examined the mechanical properties of high-temperature carbon and nickel-chromium steels, to be conducted under the joint supervision of the committee and Professor H. F. Moore at the University of Illinois.[143] In 1928 a joint research committee, with representatives from the Association of American Steel Manufacturers, the American Railway Engineering Association, the American Society of Civil Engineers, the American Institute of Steel Construction, and the ASTM, was established to study the yield point of structural steel.[144] In 1930 the ASTM steel sub-committee on steel castings considered issuing specifications for alloy steel castings "to meet a need for the rapid development in recent years of heat-treated alloy steel castings;"[145] but, because the ASTM

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[141] The Iron Age, July 2, 1925, p. 26. The study led to a 1927 agreement on the terminology to be used in describing heat treatment. The Iron Age, July 14, 1927, p. 79.

[142] The Iron Age, March 29, 1928, p. 872.

[143] The plan was to use ordinary high-temperature tension tests and long-life creep tests, as well as to test a number of alloy steels. See The Iron Age, April 3, 1930, p. 1020.

[144] The Iron Age, July 5, 1928, pp. 29-30.

[145] The Iron Age, April 17, 1930, p. 1160.

recognized that any such specifications could quickly become obsolete, they proposed to consult with the other major technical associations interested in alloys.[146] In 1930, the ASTM and the ASME followed up their earlier work by presenting a joint symposium on the effect of temperature on metals.[147]

An important series of cooperative research efforts were carried out by the ASTM and the Society of Automobile Engineers (SAE) to improve the quality of automotive steel. Automotive steel was an area of rapid technological change during these decades due to the experimentation by automakers with various alloys (See Chapter 5, below); thus specifications for automotive steels also changed rapidly. In 1917 the ASTM considered developing its own specifications for automobile steels; it advised the SAE that its specifications for automobile steels would agree with those currently issued by the SAE and that it hoped to achieve a general agreement with the SAE on specifications.[148] In 1921 the ASTM placed an SAE representative, F. P.

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[146]These associations included: the American Railway Association, the American Electric Railway Association, the American Foundrymen's Association, the American Society for Steel Treating, the National Electric Light Association, the American Petroleum Institute, the American Society for Mechanical Engineers, the Steel Foundrymen's Society of America, the Canadian Engineering Standards Association, the Bureau of Construction and Repair of the Navy, and the Army Ordnance Department. See The Iron Age, April 17, 1930, p. 1160.

[147]Many of these cooperative researches were marked by commitment of corporate funds as well as laboratory research resources. Funds for one phase of the joint investigation of phosphorus and sulphur in steel --that examining the effect of phosphorus in steel castings--were raised by the American Foundrymen's Association and the Steel Founder's Society. Some funds to support the study of corrosion of non-ferrous metals were provided by General Electric. See The Iron Age, July 5, 1928, p. 29.

[148]The Iron Age, July 5, 1917, pp. 12-13.

Gilligan, on its own sub-committee on automobile steels, while the ASTM's A. L. Colby was placed on the SAE's corresponding committee.

Consensus between the two associations regarding certain specifications was difficult to achieve, given the rapid technological changes in automotive steel; yet the ASTM persisted in working to promote more research and more standardization for automotive steel. In 1922 the ASTM steel committee began to prepare specifications for automotive steel sheets, and announced that they would continue to cooperate with the SAE.[149] In 1923 H. M. Williams of General Motors, representing both his own firm and the American Society for Steel Treating, informed the ASTM that it was not yet feasible to develop specifications for automotive sheet steel:

> developments of specifications for the inspection and test of automobile sheets is occupying the attention of many metallurgists and engineers . . . . a postponement of standardization of this important automotive material has been necessary.[150]

Yet the ASTM considered these specifications to be of great importance, both for its automaker members, by eliminating defective steel and for its producer members, by standardizing automotive sheet steel, and so it continued its efforts.[151] By 1930 the ASTM was able to sponsor a symposium on automobile materials that demonstrated considerable progress in research into automotive steels and considerable support for the ASTM's persistent efforts from automakers: General Motors' A. L. Boegehold who gave the ASTM substantial credit for promoting the

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[149]*The Iron Age*, November 30, 1922, p. 1470.

[150]*The Iron Age*, October 18, 1923, p. 1053.

[151]*The Iron Age*, October 18, 1923, p. 1053.

transition from rule-of-thumb to science in automotive steel by promoting the use of specifications:

> modern automobile foundries have discarded old rule-of-thumb methods . . . . the cause of this development is the direct result of a scientific study of fundamental principles of the foundry business.[152]

At the symposium, C. M. Johnson of Crucible Steel reported on stainless steels, noting the "promise of a great future for these steels and alloys in general, . . . in cutting down in a large way the billions of dollars lost through the rusting of ordinary steels and painting them;"[153] and W. H. Graves of Packard reported on methods of testing automotive sheet steel.[154]

The ASTM successfully helped to promote research into automotive sheet steel and other advanced topics in steel metallurgy through broad-based cooperative and collaborative research efforts with other technical associations during the late 1910s and 1920s.

Section 5. The ASTM's Contributions to Industrial Research

The ASTM provided a regular forum for the communication of research. Industrial research results were debated at the Society's annual meetings, and these debates often stimulated further research by both consuming and producing firms. As described above, in this way, the ASTM served as an important institution for disseminating research

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[152] The Iron Age, March 27, 1930, p. 930.

[153] The Iron Age, March 27, 1930, p. 931.

[154] The Iron Age, March 27, 1930, p. 931.

results throughout the steel industry. Because the ASTM actively promoted research into many industrial materials, and because it became an increasingly visible and active organization that counted influential industrial scientists among its membership ranks, the ASTM helped to promote the transition from rule-of-thumb to science in American industry in the first three decades of this century. Through its efforts, industrial testing and specification-making were made an integral part of industrial research in many firms, and many producing firms, especially steel producing firms, were gradually induced to improve their products and processes through industrial research.

a. The ASTM's Philosophy toward Industrial Research

A major goal of Charles Dudley, the ASTM's first president, was to encourage testing and specification-making as a way of promoting a transition from rule-of-thumb to science and thus to improve materials. Moreover, Dudley viewed cooperation between producing and consuming firms as a crucial element to that transition, and emphasized several points in his several presidential addresses to the ASTM that bear on the nature of cooperative industrial research: the usefulness of the interactive process, the efficacy of contention, the benefits of research for both producing and consuming firms, the importance of studying failed parts, and the importance of specification-making to industrial research.

The importance of an interactive industrial research process was that producers and consumers could work together to hammer out the requisite details needed in commercial products. Dudley was instrumental in instituting such an interactive process for the ASTM. In his view, the earliest specifications issued by consuming firms were "little more than attempts on the part of the consumer to tell the producer what he wanted."[155] An interactive process improved specifications and also made them more useful to both sides: "it became the custom to consult the manufacturer in making the specification."[156]

Admittedly, the interactive process, even if ultimately productive of useful results, was frequently antagonistic:

> . . . Not a few contests were characteristic of those days, which contests were marked on the part of the producer by wordy assertions, by appeals to business reputation and standing, and by threats of litigation, and, on the part of those in charge of the purchase and use of the goods, by a quiet determination to defend to the death the interests committed to their care.[157]

In Dudley's view, this antagonism was a crucial element of the process of improving products and processes:

> . . . so great is our belief in the value of human antagonism, where the truth is involved, that we cannot help saying that we would prefer a method which resulted from the contentions of two chemists, the one of whom was the employee of a consumer and who was trying to make out that the sample on which they were both working contained more phosphorus than the specifications allowed; and the other of whom was the employee of the producer, and who was trying to show that the phosphor in the sample was below the requirements of the specifications, there being a large commercial transaction involved in the result. We cannot help feeling that every point in the method would receive much more severe criticism, and consequently if it survived would be much more worthy of confidence under these conditions, than if it were brought out by a single

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[155]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 19.

[156]ASTM, Proceedings, 1907, p. 19.

[157]ASTM, Proceedings, Philadelphia: ASTM, 1904, p. 24.

experimenter making investigations for the sake of publishing them.[158]

One common area of contention between producing and consuming firms was that the specifications of consuming firms were too rigorous.[159] This argument was routinely discounted by consuming firms. Another common argument was that increased use of specifications would lead to higher prices, due to increased rejection of materials.[160] Dudley attempted to counter these arguments by noting that once specifications were in general use, all manufacturers would be bidding to supply material of uniform quality, and thus prices would be driven down by competition. Specifications would also ensure a steady demand for costly components so they could be purchased in greater quantities at a more economical price.[161] Another area of contention was that producers did not take kindly to consumers dictating to them about which processes to use or which products to make:

> In the earlier days, . . . the producer of any material was supposed to know not only how to manufacture it, but also its characteristics and how it would behave in service, and consequently consumers who in those days had scarcely

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[158] ASTM, Proceedings, Philadelphia: ASTM, 1905, pp. 18-19. The work of testing engineers and chemists who were employed by producing and consuming firms received more scrutiny than work performed by pure researchers, and thus was more likely to yield improvements in products and processes.

[159] ASTM, Proceedings, 1904, p. 134.

[160] ASTM, Proceedings, Philadelphia: ASTM, 1909, pp. 21-23. As Dudley observed, "it is constantly urged that the consumer will not pay the price requisite to secure the materials desired. No information is usually given as to how far the wished-for-price, requisite to secure such good materials as the producer would like to furnish, covers a desire for large profits, and consequently consumers have always been a little slow in attaching much weight to the excuse."

[161] ASTM, Proceedings, Philadelphia: ASTM, 1903, p. 134.

begun to study for themselves the behavior of materials in service, naturally turned to the manufacturers for counsel as to what materials to use . . . . as time progressed, and large consumers began to study for themselves the behavior of materials in service, as they began to employ their own experts, as testing machines and laboratories began to increase, as, indeed, a society for testing materials came into existence and knowledge of the properties and characteristics of materials began to widen, it is evident that the situation has changed, and that where materials are bought on definite specifications, the voice of the producer as to quality is no longer potent.[162]

The ASTM took upon itself the task to mitigate this last set of differences. Enforcement of specifications was a final area of contention between producing and consuming firms. In Dudley's view, it was important for consuming firms to enforce specifications, so as to induce steel producing firms to make stronger efforts to improve materials:

. . . a very large number of commercial producers as a matter of fact do not know the characteristics of their output . . . . as long as the consumers accepted the material and raised no questions, they themselves saw no need of making tests and experiments, except perchance such as would lead to diminution of cost in manufacture.[163]

Yet, despite the often contentious nature of specification-making and using, many benefits resulted. The most important benefit was inducement of incremental, cumulative improvements in products and processes by steel producers as they increased their scientific knowledge of steel. At first, steel producers were largely ignorant of the scientific basis of their production processes:

. . . again and again [we] received from producers in reply to the question whether they could make a product that would stand the tests of the proposed specifications, the answer, that they could if anybody could. There was

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[162]ASTM, Proceedings, Philadelphia: ASTM, 1909, pp. 22-23.

[163]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 25.

> apparently absolute lack of even the most rudimentary knowledge of those qualities of their product, which were of the most interest and importance to the consumer. And yet, without this knowledge, contracts are taken and shipments made.[164]

But as consuming firms added the weight of contractual commitment to specifications, producing firms began to initiate industrial research to meet specifications and to improve products and processes. Consuming firms also improved their knowledge of industrial materials by developing and using specifications. Thus specifications benefitted both sides: in Dudley's view, "a properly drawn, carefully balanced specification was a protection and an advantage to both the producer and the consumer."[165] To obtain all these benefits, it was important for consuming firms to establish the proper in-house testing facilities and procedures, and to stand their ground in making rejections: "Nothing shall be left to the honesty and good intention of the producer or shipper."[166] Consuming firms should be careful of the accuracy of their testing procedures:

> Shipments of material once fairly rejected, should never be accepted and used if the material is of such a kind that safety or risk to human life is involved, and finally, it is suicidal, as it brings with it a train of almost unmanageable subsequent conditions, to accept rejected material in which only commercial considerations are involved, unless there is some abatement in price.[167]

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[164]ASTM, Proceedings, 1907, p. 25.

[165]ASTM, Proceedings, Philadelphia: ASTM, 1904, p. 17.

[166]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 28.

[167]ASTM, Proceedings, 1907, p. 35.

One major aspect of the ASTM's industrial research was its ongoing study of failed parts: the "study of parts that had actually failed in service [was a] . . . never-ending source of valuable information."[168] In Dudley's view, because of the danger to the public when material of inferior quality failed, industrial research was no longer a luxury, but a necessity, for both consuming and producing firms:

> . . . Is not the time near at hand when engineers and their principles will be compelled if not legally then by force of public opinion, to acquire by the establishment of laboratories and means of testing, by the making and enforcement of specifications, such knowledge in regard to the materials they are putting into structures, as will give the public greater security than it now has against disaster?[169]

The study of failed materials was important because disputes over the cause of failed parts were central to many of the disputes between producers and consumers:

> Few fields of study are more fruitful of results and lead to more genuine progress than a study of the cause of failures . . . . Closely connected with the query as to the cause of failure is the ofttimes more important question, who is responsible for the failure . . . . With each and all of us it is usually the other fellow and not ourselves that should be held accountable. . . . [170]

Several solutions to the problem of failed materials emerged from the debate over steel rail failures and the interactive process of

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[168]ASTM, Proceedings, Philadelphia: ASTM, 1904, p. 28. The PRR studied a variety of steel products--boiler and fire-box steel, axle and crank-pins, spring steel, all products for which the road came to establish minimum physical limits for elongation and tensile strength.

[169]ASTM, Proceedings, Philadelphia: ASTM, 1907, p. 38.

[170]ASTM, Proceedings, Philadelphia: ASTM, 1909, p. 20.

industrial research practiced by the ASTM, that emphasized incremental, cumulative improvement in product and process. Consuming firms should test all materials:

> In time past, . . . the reputation of the maker was perhaps the best safeguard known for good materials . . . . But in these days, when the service has been so frequently questioned, when so much accumulated information is available, when experts and facilities for testing are so largely multiplied, we cannot help feeling that the management that put material into service, especially when safety is involved, without careful and conscientious inspection and testing, is taking a risk that it is no longer entitled to assume.[171]

Producers should also initiate testing procedures: "surely it is as legitimate that the producer should study the treatment his material gets in service, as that the consumer should study the methods by which the material is made."[172] Experimentation with improved products and processes, carried out in cooperation between producers and consumers, would emerge from these testing activities, and, ultimately, better materials would result.

The basic point, for Dudley, was that specification-making and industrial testing involved considerable industrial research. Preliminary research was required to determine necessary characteristics for materials. Available commercial products had to be studied before a given specification could be formulated.[173] The initial specification still contained some uncertainties, but led to further study of a given material and subsequent revisions. As use of the material expanded,

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[171]ASTM, Proceedings, 1909, p. 32.

[172]ASTM, Proceedings, 1909, p. 32.

[173]ASTM, Proceedings, Philadelphia: ASTM, 1903, p. 132.

steel consumers placed greater demands on the existing specifications, requiring further revision. Thus specification making and using promoted an ongoing process of incremental and cumulative change[114]--over Dudley's years of leading the ASTM, tremendous improvements in steel metallurgy resulted:

> How many steel makers twenty or twenty-five years ago felt sure enough of their furnaces and their methods so that they would be willing to take orders and guarantee successful output on such limits as these? It is of course not claimed or even thought that this decided step forward in steel metallurgy is wholly due to specifications, but is it too much to claim that the results now possible are in part at least due to the stimulus put upon the producer by the demands or desires of the consumer as embodied in specifications?[115]

Through his leadership of the ASTM and his encouragement of dissemination of scientific data about industrial materials, Dudley helped to promote increased use of industrial research by American industry between 1900 and 1930.

The ASTM stressed the importance of modifying specifications when new products and processes were employed in industry and when new information became available. In 1917 Stevenson argued that such

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[114]ASTM, Proceedings, Philadelphia: ASTM, 1904, p. 30. Dudley illustrated this with the example of the first PRR specifications for steel axles. These specifications limited the carbon content to between .22 % and .26 %. When a number of axles produced to comply with this specification broke, the PRR studied the problem and subsequently raised the limits to .50 %. Previously few axles were made with carbon exceeding .30 % carbon: "one steelmaker told us in plain language we were making a most serious mistake, and that we would rue it. Another opposed the proposed specification in every reasonable way possible, and only took an order under it with the utmost misgiving." A later PRR study indicated that still stiffer steel was required, requiring a further increase in carbon to .65 %; at the time no manufacturer was willing to try to make such a steel, but six months later one manufacturer finally agreed to experiment.

[115]ASTM, Proceedings, 1904, p. 29.

modifications of specifications would continue to promote the cooperative process:

> As specifications are based more and more on facts and knowledge rather than on opinion and speculation, the producer and consumer find it less difficult to work together harmoniously.[176]

Standard specifications would always be changing and might ultimately become less stringent because scientific information about materials would increase as a result of the ASTM's investigative work:

> as we gain more knowledge of materials and as new methods of testing are developed, there will be less necessity for a number of requirements that are now in our specifications, and as a consequence the specifications will be much shortened, though just as efficient. As better grades of raw material become exhausted, there is no doubt that changes in the requirements as to impurities will have to be given consideration. Personally I feel that time will show that many specifications have requirements covering impurities that are not necessary, and that materials with those requirements raised will be just as reliable as materials furnished under present specifications.[177]

Yet, as the PRR's Gibbs observed in 1915, it was not only important for the ASTM to add to specifications when new knowledge was obtained, but to remove obsolete provisions in specifications that reduced incentives for improvement--to constantly study materials and to revise specifications accordingly.[178] Clamer, a steel producing representative, agreed with this notion:

> Research should point out the ideal, namely the highest standard of excellence which should be approached as nearly as possible by the approved standard. The final specification must of necessity be a compromise between

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[176]ASTM, <u>Proceedings</u>, Philadelphia: ASTM, 1917, p. 43.

[177]<u>The Iron Age</u>, July 5, 1917, p. 10.

[178]ASTM, <u>Proceeding</u>, Philadelphia: ASTM, 1915, p. 37.

> consumer and producer, the consumer demanding the nearest approach to the ideal, and the producer agreeing to that which is commercially possible, cost, rapidity of production, service requirements, etc., all having due consideration.
>
> Research bodies should never be satisfied that the ideal which they have set up is final, otherwise practice becomes crystallized and invention discouraged.[179].

b. The ASTM's Contributions to Industrial Research in New Steel Products and Processes

The ASTM actively pursued its objectives of improving the quality of steel and other industrial materials and achieved tangible results: a large number of specifications were devised during the first three decades of the ASTM's existence--with the total number of specifications increasing from 164 in 1917 to 515 in 1927.[180] The ASTM came to be recognized as the authoritative body for standards.[181] The cooperative efforts between producing and consuming firms promoted increased research and induced more rapid improvements in products and processes, because producing and consuming firms began to establish in-house laboratories to test materials for compliance to specifications and to conduct research in support of ASTM committee work. During the first decade of the ASTM's existence steel producing firms comprised

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[179]ASTM, Proceedings, Part 1, Philadelphia: ASTM, 1919, p. 84.

[180]The ASTM was increasingly looking into making specifications for non-ferrous metals. Specifications for non-ferrous materials had increased three-fold, from 19 such specifications in 1917, to 70 in 1927. See The Iron Age, October 20, 1927, p. 1106.

[181]C. D. Young, "Condensed Information concerning the American Society for Testing Materials," Philadelphia: ASTM, 1916, p. 3.

twenty percent of the ASTM membership ranks.[112] By 1921 all but seven of the top thirty-three steel producers[113] had representatives in the ASTM as well as a large number of small steel producing firms.[114]

By inducing the establishment of in-house testing facilities at producing and consuming firms, the ASTM also helped to promote more research into ways to improve steel products, accomplishments heralded by the steel industry's trade journal, Iron Age. In 1909, Iron Age observed that, even though the expressed purpose of the ASTM was standardization of materials, significant contributions through original industrial research had been made in the field of iron and steel metallurgy.[115] During the 1920s, Iron Age editorials praised the ASTM research into steel:

> . . . a pronounced change in the activities of the American Society for Testing Materials, especially in so far as metals are concerned, is apparent. During the early years of its existence the various committees had a busy time to harmonize the differences between the desires of the producers and consumers of tonnage commodities. Satisfactory agreement having been reached on trade customs, it then became evident that many questions remained of a technical nature, and about which little or no precise information was available. Consequently the active committees at present are engaged in some research to clear up questions of fact. No less than 26 of such projects are now under way, in the field of metallic research alone.[116]

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[112]ASTM, Proceedings, Philadelphia: ASTM, various years, 1902-1910.

[113]See Thomas R. Navin, "The 500 Largest American Industrials in 1917," Business History Review, Vol. XLIV, No. 3, pp. 360-86.

[114]ASTM, Yearbook, Philadelphia: 1920, ASTM.

[115]The Iron Age, July 8, 1909.

[116]The Iron Age, July 5, 1928, p. 28. See also The Iron Age, January 18, 1923, p. 237.

In fact, during the first three decades of the twentieth century ASTM members--representing consuming and producing firms as well as academic scientists and independent engineers--were involved in increasingly sophisticated industrial research. Various aspects of research into steel metallurgy were presented at the annual ASTM meetings during its first three decades. These research efforts showcased some important pioneering work by the ASTM; and were aided by broad participation of consuming and producing firms, independent testing engineers and university scientists. Much of this research was presented at ASTM annual meetings, and information was thus disseminated throughout the industries of both producing and consuming firms.

One important new area of steel metallurgy investigated by the ASTM was alloy steel, a field largely unexplored by industry until the 1910s.[117] The ASTM provided a forum for various industrial researchers looking at alloy steels. During 1910 much of the discussion centered on copper alloys, with input from several producers--Ajax Metal's G. H. Clamer, Duplex Metals' Wirt Tassin, Halcomb Steel's J. A. Mathews, Pennsylvania Steel's J. V. W. Reynders, as well as testing engineers Robert W. Hunt and Henry Souther.[118] By 1915 attention turned to a wider array of alloy steels and their use in an increasing

[117]There were some early ASTM discussions of alloy steels: including G. E.'s Skinner in 1904 on tests on electrical alloy steels, and Lackawanna Steel's Waterhouse in 1909 on the usefulness of titanium alloys in reducing segregation in steel rails. See The Iron Age, June 23, 1904, p. 4; and ASTM, Proceedings, Philadelphia: ASTM, 1909, pp. 201-09.

[118]ASTM, Proceedings, Philadelphia: ASTM, 1910, pp. 267-73; The Iron Age, July 7, 1910, p. 36-38.

number of commercial uses, including automotive products.[189] In 1917, the ASTM sponsored a forum on various important alloys--manganese, nickel, silicon, vanadium, and chrome vanadium.[190]

During the 1920s, the ASTM actively promoted research into alloys. It organized a committee to investigate ferro-alloys in 1923 which succeeded in developing new information on the endurance and fatigue properties of alloy steels.[191] The ASTM also launched an investigation of corrosion-resistant, heat-resistant, and electric-resistant alloys, and proposed to direct the efforts of this committee away from specification-making because new alloys, and new uses for existing alloys, were still being developed: the role of the ASTM would be to gather and distribute data to its members.[192] A highlight of the 1924 meeting was the ASTM's symposium on corrosion-resistant, heat-resistant, and electric-resistant alloys.[193] In 1925, the ASTM sponsored a major study of ferro-alloys to be carried out by cooperating scientists at the University of Illinois, the Naval Experiment station, and Westinghouse.[194] In 1929 the ASTM organized a new standing committee

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[189] The Iron Age, June 24, 1915, p. 1405; ASTM, Proceedings, Philadelphia: ASTM, 1915, pp. 5-95.

[190] ASTM, Proceedings, Part 2, Philadelphia: ASTM, 1917, pp. 5-44.

[191] The Iron Age, June 28, 1923, p. 1861; The Iron Age, July 6, 1923, p. 11.

[192] The Iron Age, November 22, 1923, p. 1396.

[193] The Iron Age, June 26, 1924, p. 1869.

[194] The Iron Age, July 2, 1925, pp. 26-27.

to examine iron-chromium-nickel alloys, to promote knowledge of these alloys and to develop standard testing methods.[195]

Another new field of metallurgical investigation was steel corrosion. A few ASTM members began to study corrosion as early as 1906; these early investigations were highlighted by the work of the Boston and Maine Railroad's Snow, Columbia's Howe, and American Rolling Mill's Cushman.[196] By 1908, the ASTM had established a committee on corrosion and began to encourage more experimental work.[197] In 1911, Cushman shared American Rolling Mill's important innovation, ingot iron --an "important step in metallurgical development"[198] with its ASTM peers.

> . . . The writer is pleased to have the opportunity to emphatically record his appreciation and admiration for the determined and successful efforts to bring about this metallurgical improvement in the face of possible financial failure as well as in the face of much existing scientific opinion that the problem was an insoluble one or at best, one not worth solving.[199]

By 1912, considerable progress in the ASTM's research into corrosion had been achieved:

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[195]The Iron Age, January 17, 1929, p. 223.

[196]ASTM, Yearbook, Philadelphia: ASTM, 1910, p. 300, and ASTM, Proceedings, Philadelphia: ASTM, 1906, pp. 148-174. Cushman was an independent testing expert who was employed by American Rolling Mill as a consultant to its industrial research laboratory.

[197]ASTM, Proceedings, Philadelphia: ASTM, 1909, pp. 327-44.

[198]Ingot iron was a product of the industrial research laboratory of the steel firm with which he was affiliated, American Rolling Mill--a research project prompted by the problems experienced by many farmers with corroding steel wire fences and culverts. See ASTM, Proceedings, Philadelphia: ASTM, 1911, p. 388.

[199]Ibid., p. 397.

> . . . as the result of a systematic series of exposure tests on steel panels erected at Atlantic City under the auspices of the American Society for Testing Materials, we now know how to select intelligently materials for prime coating iron and steel.[100]

Corrosion continued to be an important area of research for the ASTM during the next two decades, with considerable financial backing provided by ASTM members:

> . . . That the interest in this subject is large is evidenced from the fact that, when the committee attempted to raise $6,000 with which to conduct the work, contributions of $10,000 were easily obtained, with much labor and all the material generously donated.[101]

By the 1920s, an extensive plan for corrosion tests of metal-coated products was organized by the ASTM in collaboration with the American Engineering Standards Committee. A new committee was organized to investigate metallic materials used for electric heating, under the leadership of Westinghouse's Harvey and Electrical Alloy's Bash; this was a research project that initiated from a 1925 meeting of electrical and steel industry representatives.[102] By 1928 the ASTM study of corrosion had produced specifications concerning corrosion of many new steel and metal products, and two new committees: one to correlate the research

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[100] The Iron Age, May 23, 1912, p. 1280. L. J. Campbell of Youngstown Sheet & Tube Company attacked Cushman's findings, calling to question the accelerated tests of metal corrosion performed by Cushman and arguing that several major manufacturers as well as the ASTM had denied the validity of such tests and noting that to date "too much effort has been expended . . . in trying to fit theories of corrosion to commercial practice. What I wish to make an urgent plea for is a comprehensive, broad-minded, unbiased investigation, free from commercialism, of the mechanism of corrosion" (p. 1281).

[101] The Iron Age, July 2, 1925, p. 27.

[102] The Iron Age, November 5, 1925, p. 1259.

results of the various ASTM committees engaged in studying corrosion and one to study stainless steel alloys.[103]

Another promising field of metallurgic research during this time was development of commercial methods for magnetic testing of steel, with the first information on the topic presented in 1908.[104] During the 1910s a leading researcher in this new testing method, Charles Burrows of the Bureau of Standards, presented his own experiments with magnetic testing of steel;[105] additional experiments were reported by Halcomb Steel's J. A. Mathews.[106] In 1919 various magnetic testing techniques for metals were featured at the ASTM's annual meeting, with Burrows and Fahy of the Bureau of Standards present to report on the

> . . . significant commercial importance [of the method]. With present methods of inspection, it is frequently impossible to differentiate adequately, without destroying the material, between ordinary and exceptional products made of the same stock.[107]

A number of applications for magnetic testing were reported, including its use in detection of transverse fissures and analysis of special steels, as well as important theoretical considerations of the relationship

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[103] The Iron Age, March 29, 1928, p. 872.

[104] Magnetic testing was a promising area for research as it promised to be a non-destructive means of testing materials. See ASTM, Proceedings, Philadelphia: ASTM, 1908, p. 137.

[105] ASTM, Proceedings, Philadelphia: ASTM, 1913, pp. 477-581; ASTM, Proceedings, Part 2, Philadelphia: ASTM, 1917, pp. 58-74.

[106] Tests considered included the Brinell and the scleroscope tests. See ASTM, Proceedings, Philadelphia: ASTM, 1914, pp. 50-74.

[107] ASTM, Proceedings, Part 2, Philadelphia: ASTM, 1919, p. 6.

between the mechanical and the magnetic properties of the steel.[108] Carnegie Steel's Unger cautioned, however, that there was yet "insufficient evidence to prove that magnetic testing has reached the point at which it will show that injurious or destructive influences are at work."[109] Through the 1920s, the ASTM continued to attempt to perfect the process;[110] the work of A. V. De Forest of the American Chain Company was singled out in 1923 as a "distinct advance in the realm of non-destructive test and inspection,"[111] and considerable information was developed on magnetic testing as a means of examining the endurance properties and fatigue resistance of alloys and steel. By 1923, Burrows, who chaired the ASTM committee on magnetic testing, observed that a number of methods for magnetic testing of steels had been introduced over the preceding few years, and he proposed that standard ASTM methods of testing be revised to include magnetic testing methods.[112] In 1926, Iron Age reported that there had been "definite progress . . . in magnetic testing of steels."[113]

The ASTM's studies of structural steel were noteworthy for two reasons: first, these important tests were conducted at important

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[108]ASTM, Proceedings, Part 2, 1919, pp. 52-67; pp. 69-94; p. 116; and p. 129.

[109]Ibid., p. 138.

[110]The Iron Age, June 30, 1921, p. 1758.

[111]The Iron Age, July 5, 1923, p. 11.

[112]The Iron Age, July 5, 1923, p. 11.

[113]Progress in magnetic testing was indicated by studies of high-speed steel by Spooner of Westinghouse and ball-bearing races by Haakon Styri of S. K. F. Industries. See The Iron Age, July 1, 1926, p. 7.

university testing laboratories, and second, the related firm--Bethlehem Steel--did not have its own testing or research facility, but, rather, relied on the ASTM to test its new innovation. In 1908 Professor Marburg reported on the tests performed at his university laboratory on the new Bethlehem Steel I beams.[114] Professor Merriman argued that more collaboration between universities and firms should be encouraged:

> It is very much to be desired that college laboratories, assisted if possible, by the manufacturers as was done in this case, should make experiments upon full-size members which are used in the various branches of engineering practice. Money for the purpose of buying testing machine for a college is often easily raised, but an endowment which shall furnish money for doing research work in a laboratory is very difficult to obtain. If such endowments can be secured it would be to the advantage of the engineering profession. Detailed tests of the strength of steel rails are especially needed.[115]

The University of Illinois laboratory and Worcester Polytechnic Institute, through the efforts of, respectively, Professor Moore and Professor Hancock, also were involved in the studies of steel I-Beams.[116]

The ASTM also researched ways to improve the quality of carbon steel during these decades. These early studies were dominated by consuming firms and outside experts rather than producing firms.[117]

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[114]ASTM, Proceedings, Philadelphia: ASTM, 1909, pp. 378-407.

[115]ASTM, Proceedings, 1909, p. 400.

[116]ASTM, Proceedings, Philadelphia: ASTM, 1910, pp. 233-45; pp. 248-57.

[117]Professor Howe reported on blowholes in steel in 1908; Professor Stoughton studied steel subjected to compression; and Professor Campbell reported on an annealing process for medium carbon steel in 1909. Professor Campbell updated his research on annealing of steel; Wickhorst of the AREA reported on low carbon streaks in split open-hearth steel rails; and P. H. Dudley of the New York Central reported on elongation and ductility tests performed with the drop-testing machines

One of the most promising areas of investigation for carbon steel metallurgy was heat treatment of steel, with the ASTM efforts beginning in 1912;[118] by 1915 increased attention was directed to quenching and heat-treatment.[119] By 1916 steel producers began to participate more actively in ASTM research into treatments for carbon steel. Carnegie Steel's Unger discussed the problems of using oil or water to cool high-carbon steels;[120] and Fry of Standard Steel Works reported on ways to treat steel forgings of low ductility so they could be used in place of forgings with high ductility.[121] By 1918 the research had advanced to increasingly technical ways to improve and test steel: microscopical

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used by some steel manufacturers in 1910. Professors Howe and Campbell reported on heat treatment for carbon steel, nickel steel, and spring steel; Professor Bradley Stoughton reported on hardness tests in 1911. A typical conclusion by consuming firms was provided by Robert Job in a 1911 report on steel tires when he observed that "it has been necessary to change the composition of the material, while in others the methods of manufacture have been improved, or, new processes devised, and in still others an entirely different structure has been substituted." See ASTM, Proceedings, Philadelphia: ASTM, 1908-1911.

[118]These studies included: the effect of the size of the section on heat treatment by J. H. Nead; and mechanical tests of heat-treated spring steel, the result of a cooperative study between the Bureau of Standards and the PRR. See ASTM, Proceedings, Philadelphia: ASTM, 1913, pp. 477-581.

[119]The Iron Age, June 24, 1915, p. 1405; ASTM, Proceedings, Philadelphia: ASTM, 1915, pp. 5-95.

[120]Young of the PRR answered this with PRR research results that the rate of cooling was more important than the medium used for cooling, noting that heat treatment of steel axles was used to secure the both suitable ductility and elasticity in the steel. The railroad's mechanical engineering department had set the allowable fiber stresses in light of the road's experience with failed axles, and therefore favored higher ductility than Carnegie's representative Unger was proposing.

[121]The Iron Age, July 6, 1916, p. 64.

analysis; electrically refined steel; deep etching of rails; and fatigue tests of nickel.[112]

During the 1920s the ASTM considered increasingly sophisticated steel research topics. In 1921 the ASTM organized a new steel subcommittee, chaired by J. M. Darke of General Electric, to study the desirable properties of sheet steel.[113] A 1925 ASTM discussion centered on advanced steel research into high temperature steel and fatigue testing, carried out on a cooperative basis by scientists at the University of Illinois, the Naval Experiment station, and Westinghouse.[114] In 1927 the ASTM reported progress in testing thin steel sheets with respect to yield point, tensile strength, and fatigue in metals; work was proceeding on summaries of the research done by the laboratories of the various member firms.[115] By 1930 the ASTM was beginning to investigate aircraft steels.[116] However, some familiar themes remained: the major discussion in 1921 concerned specifications

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[112] ASTM, Proceedings, Part 2, Philadelphia: ASTM, 1919, pp. 69-81; 81-98; 98-108; 141-56; 182-88; 206-18; and 224-37.

[113] The Iron Age, November 10, 1921, p. 1224.

[114] The Iron Age, July 2, 1925, pp. 26-27. In 1926 more advances were made in the study of fatigue in metals, both in studies by H. F. Moore at the University of Illinois, and D. J. McAdam, Jr. at the Naval Experiment Station, and in a study by P. L. Irwin of Westinghouse. See The Iron Age, July 1, 1926, p. 6.

[115] The Iron Age, July 7, 1927, p. 8; The Iron Age, April 4, 1929, p. 958.

[116] The Iron Age, July 3, 1930, p. 26.

for chilled cast-iron car wheels, a controversial topic due to the increasing derailments caused by wheel failures.[117]

Given the increased quantity and variety of research by ASTM committees, it became clear that another important function for the ASTM would be to collect and organize this information. Accordingly, in 1925 a new committee was established to correlate all ASTM research; its first major effort was the preparation of a "List of Current and Proposed Researches and Investigations of A. S. T. M. Committees:"

> there is already going on in the Society a considerable amount of worthwhile research work on the properties of materials and on the development of methods for determining such properties.[118]

Section 6. Conclusion

By 1930, through the efforts of the ASTM, making and using specifications for steel products had gained recognition as a useful activity throughout various steel producing and consuming industries. Prior to the ASTM, considerable differences existed between "manufacturers standards"[119] and consumers' specifications. Steel producers slowly changed their attitude toward consumers'

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[117] G. W. Lyndon, representative of the Association of Manufacturers of Chilled Car Wheels, noted that manufacturers in his association were interested in improving the chemical composition of their wheels, although Waterhouse of Lackawanna argued that "from a steel man's point of view, the proposed specifications would tie down makers too closely particularly in limiting the silicon content." See The Iron Age, June 30, 1921, pp. 1757-59.

[118] The Iron Age, July 2, 1925, p. 28.

[119] "Recent Advances in the Standardization of Steel Specifications," Iron Age, April 30, 1903, pp. 28-29.

specifications, moving more aggressively into industrial research by the 1920s.[130]

However, steel producers relied on steel consumers to devise most new steels during most of the first three decades of the twentieth century.[131] The backward linkage to industrial research in the manufacture and processing of steel was established through the efforts of steel consuming firms and technical associations that worked to improve steel quality. The ASTM helped to resolve some of the ongoing disputes between producers and consumers over the appropriate terms for reasonable specifications, and as such, helped to make specifications and industrial research more acceptable to both groups.[132] The ASTM labored to develop standard specifications for many industrial products with the end in view that standard specifications would lead to better materials and better manufacturing processes; toward this end, the ASTM relied on cooperation between producing and consuming firms on ASTM committees and cooperative efforts with other technical associations.

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[130]Editorial, The Iron Age, July 24, 1919, p. 250.

[131]The Iron Age, March 6, 1930, p. 720.

[132]ASTM, Proceedings, Philadelphia: ASTM, 1917, pp. 41-43.

CHAPTER 5

THE STEEL INDUSTRY AFTER 1900

Section 1. Introduction

The steel industry of the early twentieth century has often been described as non-innovative.[1] Yet, as evidenced by the material presented in preceding chapters, there was in fact considerable technological innovation occurring in steel products and processes. Most of the early innovation was induced by railroads and technical associations demanding better quality steel and imposing stringent requirements on steel producing firms. Innovation in steel products and processes came about slowly, in the form of incremental, cumulative

[1]Chandler argues that, after 1900, "[r]esearch and development played a smaller role in the continuing competition for market share than it did in any other major American industry." See Scale and Scope, p. 139. Similarly, Schroeder suggests that technological pioneering played little part in the growth of steel firms over the first few decades of this century, and that the smaller steel producing firms "have been the real pioneers in the industry, [while] . . . the largest has been somewhat slow to inaugurate new methods;" "technological initiative has been an outstanding feature of the development of only one of the major companies, namely, Armco Steel Corporation." See The Growth of Major Steel Companies, pp. 112, 211. See also Yale Brozen, "R&D Differences among Industries," Economics of Research and Development, ed. Richard A. Tybout (Ohio State University Press, 1965), pp. 85-86; Edwin Mansfield, "Size of Firms, Market Structure, and Innovation," Journal of Political Economy, Vol. 71, 1963, p. 566; Jesse W. Markham, "Market Structure, Business Conduct, and Innovation," American Economic Review, May 1965, p. 327; Perazich and Field, Industrial Research and Changing Technology, and Nestor Terleckyj, Research and Development: Its Growth and Composition (New York: National Industrial Conference Board, 1963), p. 109.

changes. Still, steel producing firms were slow to move into industrial research.

In fact, over the first three decades of the twentieth century, relatively little progress in industrial research was made in the steel industry. By 1921 few steel producers--and only seven out of the top thirty-three steel producers--had established research laboratories;[2] moreover, the two largest steel firms, U.S. Steel and Midvale Steel, had only small laboratories. Large firms in the steel industry, by contrast to large firms in other industries, were not prominent among the pioneers of American industrial research. Industrial research was still not being employed as a competitive strategy to increase market share because most steel producing firms had little financial incentive to improve steel quality or to develop new steels.

Yet innovative activities in the steel industry increased during the 1910s and 1920s, along with the demand for new quality steel products, due to both demand- and supply-side factors. On the demand-side, rails used more than half of total steel output in 1900, but only twenty-two percent by 1927.[3] Over the intervening three decades, two emerging industries--automobiles and electrical equipment--created new markets for specialty steels with precise characteristics. Steel producing firms responded by increasing their industrial research efforts. On the supply-side, there was little basic scientific knowledge about steel in 1900. Over the next two decades, steel consuming firms

[2]National Research Council, <u>Industrial Research Laboratories of the United States</u> (Washington: National Research Council, 1921), various pages.

[3]<u>The Iron Age</u>, January 6, 1927, p. 13.

conducted research into steel products and processes and issued specifications that contained their findings about the appropriate characteristics of quality steel. In so doing, they helped to create a body of scientific knowledge about steel and induced a transition from rule-of-thumb procedures to scientific methods in steel producing firms. By 1930, the importance of research as a means of learning more about the fundamental science underlying steel products and processes was widely acknowledged throughout the steel industry.

This transition from rule-of-thumb to science is seen in the incremental improvement in steel that resulted from ongoing investigations of the impurities in processed steel that caused defects in steel products, and the gradual development of scientific techniques to remove these substances. In the late 1800s, most research efforts were directed at removing phosphorus. By the turn of the century, attention turned to the harmful effects of sulphur. During the first two decades of the twentieth century, efforts turned to the harmful effects of oxygen. By the 1920s, attention shifted to a variety of potentially harmful non-metallic inclusions in steel. Steel consuming firms induced most of this industrial research: the "increased activity on this subject was very largely due to the increasingly rigid specifications of buyers, particularly in the automobile trade."[4]

Industrial research pioneers in steel like the PRR and the ASTM were among the first to use scientific methods in steel analysis and industrial research intended to solve specific technological problems in steel, and, in so doing, induced steel producing firms to make wider use

[4]The Iron Age, August 14, 1930, p. 431.

of research during the 1920s. More precisely, steel consuming firms established crucial backward linkages between engineers and chemists in steel-consuming industries and steel industry engineers and chemists. Steel consuming firms were first to be concerned about research into steel:

> . . . it became extremely important to understand such things as the notorious variability of the metal, as well as its precise performance characteristics when subjected to a wide range of new stresses, tensions, and pressures in entirely new applications. Thus, the feasibility of employing steel on a large scale, after [emphasis Rosenberg] the innovations that led to its lower price and greater supply, led to considerable research and testing by new classes of users, as well as the steelmakers themselves.[5]

But what about steel producing firms? In this chapter, sundry evidence from contemporaneous issues of Iron Age concerning the research activities of steel producing firms during the early twentieth century will be explored. The industrial organization of the steel industry will be provided as background. The general status of industrial research in the industry will be considered; and some specific information on industrial research into automotive and alloy steels will be examined.

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[5]Rosenberg, Inside the Black Box, p. 157.

Section 2. Industrial Organization in the Post-1900 Steel Industry

In 1901, U.S. Steel became the largest steel producing firm in the U.S., and remained so for several decades.[6] For this reason, the U.S. steel industry has typically been described as an oligopoly with dominant firm non-collusive price-leadership.[7] U.S. Steel controlled

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[6]U.S. Steel in 1901 controlled production of the majority of the finished steel products produced in the U.S.: seventy-five percent of steel billets and T rails, ninety percent of street railroad rails, sixty percent of all rails, eighty-five percent of structural steel, eighty percent of tin plate, eighty-five percent of wire, eighty-five percent of wire and wire products, and "substantially all of the sheet steel, tubes, and tin plating capacities;" as well, it controlled a substantial portion of steel inputs: forty-six percent of all iron ore mined in the U.S., forty-five percent of pig iron, seventy-two percent of Bessemer steel, sixty percent of open-hearth steel, sixty-seven percent of total ingots, and forty-four percent of the nation's total steel capacity. The remaining firms were much smaller: Pennsylvania Steel had 4.6 percent of industry capacity; Jones & Laughlin had 4.4 percent; Lackawanna had 4.4 percent; Cambria had 4.0 percent; Colorado Fuel and Iron Company had 3.2 percent; and Republic Iron and Steel had 2.1 percent. See Schroeder, The Growth of Major Steel Companies, 1900-1950, pp. 38, 43; and Donald O. Parsons and Edward John Ray, "The United States Steel Consolidation: The Creation of Market Control," The Journal of Law and Economics, April 1975, p. 211. Yet Hogan asserts that the capacity of the mills of the new corporation "was not as large a percentage of the total industry as has often been stated." See William T. Hogan, Economic History of the Iron and Steel Industry in the United States (Lexington, Massachusetts: Lexington Books, D. C. Heath and Co., 1971), p. 480.

[7]Dominant firm non-collusive price leadership refers to an oligopolistic industry in which the dominant firm has the ability, by virtue of its dominant market share (defined as fifty percent or more of the market), to set price for the industry. The dominant firm will select the most profitable price for its commodities. Smaller firms take this price as given, but when prices are relatively high (i.e., when economic profit can be made), they expand capacity to take advantage of the higher price. Over time, as the dominant firm seeks to maintain the higher price rather than retain its original market share, its market share will decline while the market share of the smaller "fringe" firms will increase. See, for example, William L. Baldwin, Market Power, Competition, and Antitrust Policy (Homewood, Illinois: Richard D. Irwin, Inc., 1987), pp. 226-29; Hideki Yamawaki, "Dominant Firm Pricing and Fringe Expansion: The Case of the U.S. Iron and Steel Industry," Review of Economics and Statistics, August, 1985, p. 429; Lamoreaux, The Great

prices throughout the industry--explicitly from 1907-1911 through the famous Gary dinners, and implicitly for decades thereafter through "a tradition of lock-step followership behind U.S. Steel's price leadership."[8] Steel prices remained stable throughout the early decades of the century under U.S. Steel's price leadership--in one important example, steel rails remained at a price of $28 per ton for many years.[9]

U.S. Steel's price leadership was maintained even as its market share declined and total capacity of the steel industry expanded during the early twentieth century.[10] Proportionate expansion for U.S. Steel

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Merger Movement in American Business, 1895-1904, p. 118-126, 135-158; and F. M. Scherer, Industrial Market Structure and Economic Performance (Boston: Houghton Mifflin Company, 1980), pp. 178-180.

[8]F. M. Scherer, Industrial Market Structure and Economic Performance (Boston: Houghton Mifflin Company, 1980), p. 178. Adams also points out that "[t]he corporation remained sufficiently big, however, to keep its competitors 'in line' without threats and without displays of force"--a form of "friendly competition." See Walter Adams, "The Steel Industry," in Walter Adams, ed., The Structure of American Industry (New York: The MacMillan Company, 1954), p. 152.

[9]U.S. Steel maintained that stable prices were good and believed that dissemination of information regarding steel prices to other steel producers was important: this was "quite apparent in testimony by major figures before Congress during the early post-merger years." See Parsons and Ray, "The United States Steel Consolidation: The Creation of Market Control," p. 208. Price stabilization was an explicit goal of the new corporation in Berglund's view: "[f]or the development of a large and well-established iron and steel business, price stabilization would therefore be a natural and farsighted policy. . . . a great combination is organized primarily to regulate or restrict competition and, therefore, production. The object of such a consolidation is not so much a better adaptation to market conditions as control of those conditions. . . . [i]ts attitude, furthermore, toward independents has never been characterized by any attempt at what is called destructive competition." See Abraham Berglund, "The United States Steel Corporation and Price Stabilization," Quarterly Journal of Economics, November 1923, pp. 5, 29.

[10]Parsons and Ray however argue that the "'dominant firm' hypothesis is incomplete . . ., particularly in its depiction of U.S. Steel's passive relationship with the other major steel producers," and they

was constrained "by various factors, . . . managerial, financial, or antitrust."[11] U.S. Steel was aware that its dominant position in the steel industry made it a likely target for dissolution under the Sherman Antitrust Act and, therefore, it fostered conservative price and expansion policies.[12] As well, U.S. Steel was not a technological trailblazer:[13] there was little reason to innovate to increase market share.

Conditions in the industry changed during these years, however. There was a shift in demand from heavy steel products such as rails and beams to lighter sheets and strips. There was a decline in Bessemer production and an increase in open-hearth production. U.S. Steel's relative lack of technological innovation gave smaller, more innovative producers an advantage in the markets for new steel

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note two distinct facts: U.S. Steel controlled much of the nation's iron ore and coke capacity and the "competitive fringe" was not composed of many small firms close in size to one another, but included several other firms "sufficiently large to make collusive pricing feasible." See "The United States Steel Consolidation: The Creation of Market Control," p. 206.

[11]Yamawaki, "Dominant Firm Pricing and Fringe Expansion: The Case of the U.S. Iron and Steel Industry, 1907-1930," p. 434. See also Abraham Berglund, "The United States Steel Corporation and Industrial Stabilization," Quarterly Journal of Economics, August 1924, p. 612.

[12]Chandler, Scale and Scope, p. 136. Moreover, U.S. Steel at the time of its formation was essentially a holding company; the firm did not undertake administrative consolidation of the activities of its various subsidiaries until the 1930s. See Chandler, The Visible Hand, p. 361. Schroeder adds that Judge Gary's principal task was to "preserve an existing enterprise, whose formation represented the largest aggregation of properties under a single control known to this country at the time, and whose birth was followed by a storm of public criticism." See The Growth of Major Steel Companies, 1900-1950, p. 44.

[13]Louis Galambos, "The American Economy and the Reorganization of the Sources of Knowledge," p. 276.

products;[14] and U.S. Steel experienced a relative decline in its market position.

Relative stability reigned in the rest of the steel industry.[15] Expansion in total steel demand was accommodated by expansion of existing smaller firms rather than by entry of new firms. The primary impetus for expansion came from major new technological innovations--larger open-hearth furnaces, larger blast furnaces, and the continuous strip mill--directed at large-scale production, establishing higher barriers to entry in the form of the large capital investments required

[14]For example, such important innovations in the twentieth century as continuous rolling mill process, alloys, use of scrap rather than new ore--were all pioneered by other steel producers. See Adams, "The Steel Industry," pp. 156-57; and Hogan, Economic History of the Iron and Steel Industry in the United States, p. 480. However, Charles Van Hise asserted that "[t]he magnitude of the [U.S. Steel] corporation had enabled it to keep a strong investigating department for improvements, mechanical and chemical; and this department has carried on extensive experiments which could not have been undertaken by a small company. Through the investigating department many advances have been made." See Concentration and Control: A Solution of the Trust Problem in the United States (New York: The MacMillan Company, 1912), p. 135.

[15]In 1904 the firms ranked (in terms of their total ingot capacity) behind U.S. Steel included: Pennsylvania Steel; Jones and Laughlin; Lackawanna; Cambria; Colorado Fuel and Iron; Republic; International Harvester; Tennessee Coal, Iron, and Railroad; Maryland Steel; and La Belle Iron. Only a small change in the rankings had occurred by 1916: Jones and Laughlin was now second, followed by Pennsylvania, Bethlehem, Cambria, Lackawanna, Republic, Youngstown, Colorado Fuel and Iron, and Inland. Only eighteen different steel producing firms were represented among the top ten steel producers in the years between 1904 and 1948. The eight firms that disappeared, did so through merger with larger steel producing firms. By 1930, Bethlehem and Republic moved up sufficiently in the rankings to become part of the 'Big Three. See Parsons and Ray, "The United States Steel Consolidation: The Creation of Market Control," p. 211; and Schroeder, The Growth of Major Steel Companies, 1900-1950, pp. 36, 96, 197-99.

to start up steel producing firms; and this favored expansion of existing firms.[16]

The steel industry could thus accurately be described as a stable dominant firm oligopoly during the first decades of the twentieth century. These stable oligopoly conditions in the steel industry provided little financial incentive for major innovations on the part of leading steel firms. However, major shifts in the nature and quality of the steel products demanded by new and old steel consuming firms induced incremental, cumulative innovation on the part of most steel producing firms, large and small.

Section 3. Technological Change in the Post-1900 Steel Industry

a. Introduction

In the last decades of the nineteenth century and the first decade of the twentieth century, a large part of the research efforts of such important steel consuming interests as the Pennsylvania Railroad and the ASTM were directed at steel rails. As a result of the increasingly stringent demands of steel consuming firms and technical associations, steel producing firms increased their research activity; yet this research by steel producing firms remained at a low level. In the twentieth century important new steel consuming industries emerged. The demands by automakers and other new steel consuming firms for

[16] Schroeder, The Growth of Major Steel Companies, 1900-1950, p. 203.

better quality alloy and carbon steels occurred when steel producing firms had already reluctantly initiated their slow transition from rule-of-thumb to science; and as a result, they were more receptive to these new steel consumers who wanted to use industrial research to improve steel. The increased levels of research in the steel industry by 1930 and two developments in steel products--automobile steels and alloy steels--illustrate this change in attitude by steel producers.

b. Industrial Research Activities by Steel Producing Firms, 1900-1930

A 1912 Iron Age survey on recent improvements in steel reported that a considerable number of steel producing firms had initiated industrial research to improve the quality of their steel and to meet the specifications of steel consuming firms.[17] Many of these steel producing firms gave the credit to steel consuming firms: three examples will illustrate. Harry Jones of the United Steel Company credited the automobile industry with prompting more research by steel producers who wished to compete with foreign producers who made high quality steel:

> The wonderful growth of the automobile industry in this country has probably had more to do with creating higher grade steel than any other factor. A small group of steel companies has in recent years given attention to the development of high grade steels, particularly in the alloy steels such as nickel, chrome nickel and chrome vanadium. . . . . The automobile companies simply had to have a high grade steel for their gears, driving shafts, axles, drop forgings, etc. Formerly, they used to import alloy steel from Germany, and paid a very high price for it. In fact,

[17]The Iron Age, January 4, 1912, pp. 41-50.

> some of them do yet, although they can get a better steel for very much less in this country.[18]

Similarly, Carnegie Steel noted that a new method for heat treatment of steel axles was prompted by railway engineers asking for harder steel: "[t]o meet this demand, this company has prepared itself to furnish, at some extra cost, almost any grade of material desired by the purchaser."[19] E. W. Pargny of the American Sheet & Tin Plate Company acknowledged that the requirements for quality steel developed by steel consuming firms had induced increased research by his firm as well:

> To satisfactorily meet exacting requirements of these specialties the steel manufacturer has been obliged to spend large sums of money to provide the necessary means looking toward quality rather than quantity. Completely equipped research laboratories, technical experts in both the steel producing and finishing departments, to say nothing of a specially trained corps of inspectors, are some of the features introduced to solve the problem of quality, so essential in this rapidly moving epoch of new idea involving the extensive use of metals, which are every day displacing materials of frail construction, thereby promoting permanency as well as safety.[20]

In attempting to meet the increasingly rigid requirements of steel consuming firms, a transition from rule-of-thumb to scientific methods occurred in many steel producing firms:

> The steel companies have been very broad-minded in giving out information concerning their steels, analyses, proper heat-treatment, etc. Years ago many steel companies made as much a mystery as possible of their analyses, manufacturing methods and heat-treatments. That day is

[18] The Iron Age, January 4, 1912, pp. 42-43.

[19] The Iron Age, January 4, 1912, p. 45.

[20] The Iron Age, January 4, 1912, p. 49.

past. The steel companies are taking the consuming public fully into their confidence.[11]

A crucial aspect of the transition from rule-of-thumb to science for steel producing firms was implementation of systematic and scientific techniques to analyze every aspect of steel production--including older techniques such as chemical and physical testing and newer methods such as scientific sampling and complex methods of treating finished steel products.

Chemical analysis was gradually introduced to steel producing firms. A 1917 Iron Age editorial commented that the use of chemical analysis was a fairly recent development: "[i]t is not many years since steel was made without the aid of a chemist to regulate its composition. Now his assistance is indispensable."[12] One reason that the use of chemical analysis increased was the transition from the Bessemer to the open-hearth and electric processes, which required greater care by steel producing firms:

> . . . [i]t has become the very general practice in open-hearth and electric steel works to send a preliminary or bath sample to the laboratory for a rapid analysis which enables the melter to calculate the additions of alloys which are necessary to bring the steel to chemical specifications before tapping the heat.[13]

Steel producing firms recognized that they had could no longer rely on visual inspection or other old rule-of-thumb techniques:[14]

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[11]The Iron Age, January 4, 1912, pp. 42-43.

[12]The Iron Age, March 1, 1917, p. 550.

[13]The Iron Age, June 27, 1918, p. 1645.

[14]Although it is interesting to note the comments of a representative of Scovill Manufacturing in 1918 on the occasion of the establishment of its lab for the purposes of conducting physical and

> . . . [i]t is false economy to place a 'rule of thumb' man in the preliminary laboratory. He should have sound technical training, actual analytical experience and should be sufficiently ingenious to work out simple devices which facilitate accuracy and speed. The chemist analyzing preliminary samples has considerable responsibility, because a slight error on his part may easily result in an 'off analysis' heat. The melter and the preliminary chemist should cooperate very closely, as the production of good steel depends upon their results.[15]

New scientific techniques for sampling and steel-treating also required adjustments by producing and consuming firms alike. William Mainwaring, a chemist and metallographist active during the 1910s, observed that defective steel was not always due to faulty steel manufacturing, but was frequently due to the fact that systematic sampling techniques were not yet routinely employed by either steel consuming or producing firms. In one case, a controversy erupted over the sampling technique used for a group of steel billets found to be badly segregated because "the claim being made [was] that the method of drilling billets used was very favorable to the steel company."[16] More scientific steel treating methods were needed as well: in one case, a customer complained that he was getting "hard and brittle"[17] steel; analysis showed that the steel was fine but had been overworked in the finishing process. In a second case, annealed steel bars were found to

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chemical tests of all products and materials used by the firm. A staff of forty chemists was created, as well as a group of "young women . . . introduced for the routine work in brass analyses. Though not chemists in any sense, they have proved very satisfactory and the excellent work they have done indicates a field of usefulness in which women can safely be placed." See The Iron Age, April 4, 1918, p. 858.

[15]The Iron Age, June 27, 1918, p. 1645.

[16]The Iron Age, July 25, 1912, p. 184.

[17]The Iron Age, July 25, 1912, p. 186.

be defective when tested; however, it was determined that the steel again was fine but that the annealing procedure had been over-used, producing segregated steel.[28] Specifications of consuming firms did not always address these potential problems.

Another aspect of the transition from rule of thumb to science in steel producing firms was increased use of microscopical analysis of steel. One steel producer, the American Sheet and Tin Plate Company, used microscopical analysis for steel sheets as early as 1912, finding it to be more useful than chemical analysis for detecting defects and several steps above mere visual inspection.[29] In 1913 Iron Age praised microscopical analysis as providing more precise information on impurities in steel[30] and declared the microscope to be a "necessary adjunct to successful metallurgical work . . . . nearly as necessary to the progressive steel maker and foundryman as a chemical or physical laboratory."[31] When, in 1913, Iron Age reported on the metallurgical studies of Albert Sauveur of Harvard, it noted that there were now "thirty-five metallurgists using the microscope in their work, including practically every steel mill of importance."[32] By 1917, an Iron Age editorial observed that the metallographist was becoming as indispensable as the chemist in steel production: "the microscope is explaining many hitherto mysterious steel failures and is the direct

[28] The Iron Age, July 25, 1912, p. 186.

[29] The Iron Age, November 14, 1912, p. 1148.

[30] The Iron Age, January 23, 1913, p. 241.

[31] The Iron Age, October 16, 1913, pp. 840-41.

[32] The Iron Age, June 5, 1913, p. 1371.

factor in the improvement and life of many steel products."[33] In 1926 Iron Age observed that "[t]o the maker of alloy steel of the quality to meet the requirements of the automotive industry, it has become indispensable."[34]

To house these analytical activities, a number of steel producing firms established in-house industrial research laboratories in the first three decades of this century. As well, most of the smaller steel-producing firms specializing in alloy and tool steels hired metallurgists between 1900 and 1920, arguing that "in many cases, however, these metallurgists were engaged in 'trouble shooting' rather than in research work."[35] Only a few large steel producing firms[36] established industrial research labs before 1920--the third largest, Midvale, in 1901; the seventh largest, Youngstown, in 1917; the tenth largest, Inland Steel, in 1894; the eighteenth largest, American Rolling Mill in 1903;[37] the twentieth largest, Sloss-Sheffield in 1915; the twenty-ninth largest, Columbia, in 1910; and the thirty-third largest, Taylor-Wharton, in 1892.

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[33]The Iron Age, March 1, 1917, p. 551.

[34]The Iron Age, September 2, 1926, p. 572.

[35]Sisco, "Research in the Iron and Steel Industry," p. 162.

[36]By largest firms I mean those firms ranking in Navin's ranking of the top 500 U. S. firms as of 1917. See Thomas R. Navin, "The 500 Largest American Industrials in 1917," Business History Review, Vol. XLIV, No. 3 (Autumn 1970), pp. 360-86.

[37]The American Rolling Mill lab is often described as the first true industrial research laboratory in the steel industry, or the first lab recognized as such. This may result from the bias against testing as industrial research. See Bartlett, "The Development of Industrial Research in the United States," p. 58; see also Christy Borth, True Steel: The Story of George Matthew Verity and His Associates (Indianapolis, Indiana: The Bobbs-Merrill Company, 1941).

During the 1920s, many other steel producing firms established research labs: the second largest, Bethlehem Steel, in 1926; the largest and fourth largest firms, U.S. Steel and Jones & Laughlin, in 1927 and 1928; the fifth largest firm, Republic, in 1930; the fourteenth and twenty-first largest firms, American Steel Foundries and Wheeling Steel, in 1926; and the twenty-sixth largest, John A. Roebling's Sons, in 1930. In total, of the top thirty-three steel producing firms in the U.S., only fourteen established industrial research labs by 1930.

The relative slowness of large steel-producing firms to establish full-fledged industrial research laboratories was due in part to their reliance on customary rule-of-thumb methods throughout the early decades of the twentieth century. Prior to the twentieth century, most innovations in the steel industry were introduced through the efforts of "rule-of-thumb" men.[38] Steel was an older industry "which existed long before the science of their art had been developed,"[39] and steel producers were more conservative in their approach to research:

> for nearly a hundred years steel making and the processing of steel into finished and semifinished products has been an art in which skills of a high order have been developed.[40]

When Iron Age reviewed the National Research Council report on industrial research in the U.S. in 1927, it too concluded that "Steel Is

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[38]Kendall A. Birr, "Science in American Industry," in David D. Van Tassel and Michael G. Hall, eds., Science and Society in the United States (Homewood, Illinois: The Dorsey Press, 1966), p. 41; Rosenberg, "The Commercial Exploitation of Science by American Industry," p. 27.

[39]Frank B. Jewett, "Industrial Research," National Research Council, Reprint and Circular Series of the National Research Council, No. 4, p. 15.

[40]Sisco, "Research in the Iron and Steel Industry," p. 162.

Not Conspicuous."[41] Industrial research laboratories in the steel industry were described as "relatively few" and "small"[42]--there were only forty-seven labs in the entire industry, with an average of only six persons working in each lab. By contrast, in non-ferrous metals, there were seventy-four labs, with an average of eight employees in each lab; in the automobile industry, there were forty-five labs with an average of eighteen employees in each lab; and in machinery, there were one hundred and fourteen labs, with an average of fourteen employees in each lab. U.S. Steel's new lab was ranked twenty-sixth in the country, but, with only sixty-six employees, was small in comparison to the largest labs--Bell Labs with 2,000 employees, du Pont with 943, General Electric with 672, International Harvester with 619, and Goodyear with 484.[43] Iron Age concluded that

> [e]vidently metallurgical advances, except perhaps in non-ferrous metals, come more from demands arising in the consuming interests than from developments originating with producers.[44]

And, by 1930, many knowledgeable observers agreed with the Iron Age conclusions that the steel industry had devoted too few resources to fundamental scientific research in steel. In 1928, W. H. Hatfield stated that

> many of the simplest expedients in the [steel] industry are archaic, and how relatively backward is science in supplying

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[41]The Iron Age, September 1, 1927, p. 567.

[42]The Iron Age, September 1, 1927, p. 567.

[43]The Iron Age, September 1, 1927, p. 567. However, Iron Age notes that the number of employees for the Carnegie Steel Co., a subsidiary of U.S. Steel, were not included in this total.

[44]The Iron Age, September 1, 1927, p. 567.

the knowledge of natural law necessary for advancement.[45]

Arthur Little agreed, and argued that steel-producing firms had, for too long, permitted steel-consuming firms to take the initiative:

> Although the steel industry has long maintained a hundred or more metallurgical and control laboratories, it has for the most part depended for research upon such outside agencies as the Bureau of Mines, the Bureau of Standards, and the Iron Alloys Committee of the Engineering Foundation, and individual workers in the universities and technical schools. With corrosion losses estimated at $3,000,000,000 a year; with admitted ignorance of many of the factors fundamentally concerned with the operation of its processes and the quality of its products; with new and extraordinarily effective instruments and agencies for investigation ready to its hand; and with suggested possibilities hitherto undreamed of close ahead, it would seem that the time had arrived for the iron and steel industry to be definitely committed to a comprehensive, well-coordinated program of research upon a scale worthy of an industry which supplies the material basis of our civilization. . . .[46]

Yet John Johnston, head of U.S. Steel's new central industrial research lab, continued to complain about the rigid chemical specifications issued for materials, arguing that they were not "justifiable" and echoing his 1900 steel industry predecessors:

> . . . the purchaser is really interested in the structure of the material supplied; and need not care what elements are present provided that the material fulfills his requirements as to mechanical qualities such as strength or ductility. This leads one to wonder whether chemical specifications

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[45] The Iron Age, May 15, 1930, p. 1459.

[46] The Iron Age, May 15, 1930, p. 1460. However, Waterhouse of MIT, in response, that "[t]he steel industry is so vast that certain lines of research are not fully appreciated, but rapid advances have been and are being made in tool steels, alloy steel and alloy cast iron, heat treatment and the physical metallurgy of steel. . . . The main contribution of science to the steel industry has been the cultivation of scientific methods in laboratories and plants, and today technical men occupy many of the authoritative positions. . . . a great deal of careful scientific work has been carried on and applied and much literature is being published as the result."

> have not attained their present vogue because it has proved to be more difficult to set up entirely adequate physical or mechanical tests.[67]

Johnston discounted recent debates over the relative merits of Bessemer and open-hearth steel because few analysts could distinguish between the two steels with certainty. As well, he argued that the chemistry of the steel frequently met specifications, but poor fabricating or improper heat treatment ruined the steel.[68]

It may be surprising, on the surface, that more steel producing firms did not attempt to set up research labs to control and direct, to their advantage, the slow, cumulative, technological changes in steel products and processes occurring in the first three decades of the twentieth century. But it is noteworthy that all but six of the largest thirty-three steel-producing firms had affiliations with the American Society for Testing Materials[69]--in some cases, steel producing firms sent sizable contingents of industrial research staff persons. Thus many steel-producing firms were at least engaging in sufficient research to meet specifications of consuming firms and to participate in ASTM committee work.

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[67] The Iron Age, May 22, 1930, p. 1536.

[68] The Iron Age, May 22, 1930, p. 1537. Dr. Gillett countered Johnston's remarks: "no specification is sacred;" and argued that continued research generally resulted in changed specifications, that some specifications were unsatisfactory due to the fact that there were as yet no quick tests nor sufficient data on which to base specifications, and that imposition of both chemical and physical requirements was "being abandoned in principle by most specification-making bodies, at least when a finished product is in question."

[69] See ASTM, Yearbook (Philadelphia: ASTM, various years).

Thus, many steel-producing firms did establish research labs, although these labs may have been viewed as primarily involved in conducting routine testing, grading and standardizing activities rather than in conducting research to meet specifications of their steel customers. However, it is reasonable to assume that many steel-producing and steel-consuming firms were in fact conducting industrial research, but may not have perceived their activities as such due to an increasing bias that industrial testing of materials was not industrial research.

Industrial research continued to increase in the steel industry during the next decade: even during the depression decade of the 1930s, the average expenditure for research in the steel industry increased ten-fold, and much of this research continued to be conducted in cooperative fashion:

> . . . the technical staffs of the industry carry out considerable research jointly with the users of steel and act as consultants to steel consumers who have no research laboratory of their own. [58]

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[58] "Although considerable cooperative research is done by the iron and steel industry of the United States, this phase of research had not been developed to such an extent as in Germany and England. Research for the benefit of the entire industry, for which the industry as a whole supplies the funds and institutes and universities supply the facilities, is the weakest phase of ferrous metallurgical research in the United States." See Sisco, "Research in the Iron and Steel Industry," p. 157.

c. Automobile Steel

By 1927, output of automobiles had increased to 275,000 new cars each year, creating a new and large group of steel-consuming firms.[51] Over the first three decades of this century, automakers shifted from wooden to steel auto bodies; and by 1927 automobile sheet steel became an important item in the steel industry--constituting thirty percent of total steel demand.[52] An Iron Age editorial in 1925 observed the impact of increased demand for automobiles on innovation in steel products and processes; particular emphasis was placed on alloy steels because twenty-five years earlier,

> . . . [the] automobile was practically a non-consumer of steel or other metals. . . . the automobile industry has been a creative factor in metallurgy. Much, but by no means all, of the steel which goes into it is sheets. It has developed no small demand for alloy steels. Only 15 years ago alloy steel making was in its infancy and the more prominent steels of today were almost unknown.[53]

Steel consuming firms had been the industrial research pioneers again:

> . . . the demands of the automotive interests for steels of high quality has [sic] given impetus to the alloy industry, of which grade steel the automobile manufacturers consume about 95 per cent. . . . In most of these developments, the initiative has been taken by the automobile interests, while the steelmakers acquiesced to their demands.[54]

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[51]The Iron Age, February 21, 1907, p. 586; January 20, 1908, p. 590; January 6, 1927, p. 60; and January 15, 1925, p. 225.

[52]The Iron Age, January 6, 1927, p. 60.

[53]The Iron Age, January 15, 1925, p. 225.

[54]The Iron Age, January 6, 1927, p. 14.

Over the first three decades of the twentieth century, the steady increase in automobile production gave tremendous impetus to research to develop specialty and alloy steels.

In 1900, the potentially large market for automotive steels was ignored by American steel producers. In 1903, only cold-rolled, low-carbon Bessemer steel was available for most automobile components--steel considered unreliable for use in automobile bodies. Automakers were not yet aware of the benefits of making and using specifications to get better quality steel and to obtain specific performance qualities in steel: "in the eyes of the automobile manufacturer at that time, steel was simply steel."[55] Steel alloys were used but considered as luxuries: among the advertised improvements for higher-priced automobiles in 1905 was the high quality metal being used for decorative components--chrome and chrome-nickel steels.[56]

By 1905, automakers began to reconsider their use of plain Bessemer steel and moved into the use of alloy steels. As Iron Age reported,

> . . . [i]n the development of motor cars it has been found that the materials commonly available in the market are not satisfactory in many respects. . . . in an automobile there are in addition to the load stresses shock stresses due to the impact of the moving machine with stones or other irregularities in the road.[57]

Automakers learned that open-hearth and alloy steels were better quality steel. The changing conditions of automobile use and an

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[55] The Iron Age, July 24, 1913, p. 172.

[56] The Iron Age, August 3, 1905, p. 293.

[57] The Iron Age, February 23, 1905, p. 669.

increasing awareness of the usefulness of specifications in obtaining the desired physical and chemical characteristics for automotive steel, led automakers to begin to request special steel. Nickel, chrome-nickel, manganese and heat-treated steels were increasingly used as well as carbon steels--but even the carbon steels used were not the "ordinary market product."[58] Many automakers imported steel to get the quality that they desired:

> [i]t is no longer the practice to purchase the best metal the market affords, but to purchase heats of special metal possessing properties not usual to the run of products to be had from stock. In some cases the metal is the product of foreign mills, simply because American mills have overlooked the motor car trade or do not care to experiment with the grades of metal that are most desirable in motor cars.[59]

To retain their domestic market, American steel producing firms had to change their products and processes. Producers supplying steel to the automobile industry were required to produce longer and wider steel sheets from which automobile frames could be made and to develop stronger alloy steels for larger and faster automobiles.

Progress was slow. In 1908 an Iron Age editorial observed that American steel producers had failed thus far to meet automakers' demand for better steel, noting that "[t[he inability to place entire reliance on materials has been a serious obstacle to automobile design."[60] However, Iron Age believed that improvements were on the

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[58]The Iron Age, August 3, 1905, p. 293.

[59]The Iron Age, February 23, 1905, p. 669.

[60]The Iron Age, November 19, 1908, p. 1452.

way, due to the increased understanding of chemistry by steel producers:

> [t]he chemist is playing an important part in this work. Not only have his services been necessary in discovering the alloys which give the desired results, but in some establishments he is constantly employed in testing the steel that enters into the construction of working parts which have to withstand the severe strains. . . . very exact knowledge of materials is required. . . . [t]he result of these researches and discoveries are finding their way into machine tools and other mechanisms.[61]

As with rails, most early efforts to study automobile steels were undertaken by automakers or technical associations. In 1910 the major technical association for the fledgling automotive industry, the Society of Automobile Engineers (SAE), issued their first specifications for a wide variety of automobile steel products; these were described as "the most complete list of materials specifications ever made for motor car engineering works."[62] The SAE specifications were praised by Iron Age as providing benefits to steel producing firms as well:

> . . . [t]o meet the imperative demands of the automobile industry there has at last been set on foot a movement looking to its permanent standardization. . . . Proper standardization will mean a tremendous saving to the industry and the public, for it spells efficiency, bettering quality, reducing cost, and facilitating production.[63]

By 1915 a number of prominent steel producing firms had joined the Iron and Steel Division of the SAE.[64]

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[61]The Iron Age, November 19, 1908, p. 1452.

[62]The Iron Age, June 30, 1910, p. 1531.

[63]The Iron Age, September 8, 1910, p. 573.

[64]These steel producing firm representatives included the following: Radclyffe Rurness, Midvale Steel; J. A. Mathews, Halcomb Steel; George L. Norris, American Vanadium; J. H. Parker, Carpenter Steel; C. F. W. Rys,

Another decade elapsed before additional steps were taken toward universalizing automotive alloy steels. In 1921 the SAE revised its first classification scheme, now viewed as "unscientific, arbitrary, and not inherently capable of wide expansion,"[65] to cover the rapidly increasing types of alloy steels.[66] The SAE changes made did not go far enough for some automakers: as of 1926, Ford used more rigorous specifications than those of the SAE. Ford used the SAE specifications as the basis for its own specifications but from there had "built up its own specifications and . . . the tendency is to buy material on finer lines than covered in the standard specifications."[67]

Individual automakers began to establish in-house labs in the 1910s to obtain quality steel, just as the PRR had done four decades earlier. In 1912, Iron Age reported on the well-equipped chemical lab of Dodge Brothers, which analyzed all raw materials purchased and tested all output produced to guarantee the strength of materials used in Dodge cars.[68] A similar report in 1913 described the laboratory of the

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Carnegie Steel; G. W. Sargent, Crucible Steel; Henry Souther, Ferro Machine and Foundry. See Society of Automotive Engineers, Membership (Society of Automotive Engineers, 1915).

[65] The Iron Age, September 1, 1921, p. 516.

[66] The Iron Age, September 1, 1921, p. 515.

[67] The Iron Age, November 25, 1926, p. 1491. Ford however did not specify physical properties for its sheet steel, "having decided that the best test for this steel is the die that is to form the part. Thus the die becomes a testing machine. This has worked satisfactorily, although it is open to the objection that the plant passes the 'buck' back to the steel mill to supply steel with the proper physical properties."

[68] The Iron Age, April 4, 1912, p. 861.

Studebaker Corporation, a lab performing similar activities, with separate chemical, metallographical, and physical testing departments where

> . . . quite a number of men are engaged in analyzing, explaining and testing the various kinds of materials and apparatus that enter into the construction of the complete motor car. The department has been made a practical commercial proposition and the work done is of the kind that has a direct bearing on the quality of materials purchased for the work done throughout the different shops of this factory. It is needless to say that savings are effected in many ways in the cost of production and these pay many times over for the cost of operating the laboratory in the course of a year.[69]

Both the Dodge and Studebaker labs analyzed materials used in automobile manufacture to guarantee that they would be "durable and as light as the strength required for the various parts will allow."[70] The Studebaker lab also developed new steel products for use in its automobiles: one example was a bearing alloy. Studebaker had previously purchased bearing alloy material "of the 'special secret composition' kind so often encountered in metallurgy,"[71] on the strength of a salesperson's pitch; but, when the metal was analyzed, it was found to be no more than a "good grade of babbitt metal, although its cost was several cents a pound higher, the additional price probably being charged for the copyrighted name."[72] Studebaker developed a satisfactory material in its own lab to avoid paying such spurious costs.

Although new products were developed by automakers, most of their research efforts were devoted to testing materials to ensure that

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[69] The Iron Age, August 21, 1913, p. 387.

[70] The Iron Age, August 21, 1913, p. 387.

[71] The Iron Age, August 21, 1913, p. 387.

[72] The Iron Age, August 21, 1913, p. 387.

steel producing firms were producing materials that met their specifications. The extensive set of chemical, metallurgical and electrical labs established by Chrysler in the early 1920s exemplified this.[13] The Chrysler metallurgical lab was devoted to establishing

> . . . the required quality of materials entering into the construction of car parts, by developing suitable production processes and determining materials standards. . . . [and checking] specimens of incoming production materials, as an assurance that the specifications have been met.[14]

But the Chrysler labs also engaged in some amount of product development: the metallurgical lab experimented with heat treating of sample materials and performed metallographic analysis of various steels while the chemical lab devoted much effort to studying the effects of corrosion on alloys.[15]

Specifications for automobile steel improved the quality of automobile steel by the mid-1920s. Yet some fundamental metallurgical questions remained unanswered. Automakers required steel with a high degree of homogeneity, and testing and specification-making by automakers helped to bring about some improvement. Steel producing firms were induced to cooperate with automakers if they wished to sell their steel, some quite willingly: W. J. MacKenzie of Interstate Iron & Steel Company praised automakers for their efforts:

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[13] The Iron Age, March 28, 1929, p. 876; and National Research Council, Industrial Research Laboratories of the United States (Washington, D. C.: National Research Council, various years).

[14] The Iron Age, March 28, 1929, p. 878.

[15] The Iron Age, March 28, 1929, p. 878. The Chrysler engineering department was the largest in the automobile industry, and was comprehensive in nature, with chassis and body design facilities; drafting, building and assembling departments; several laboratories--for electrical, chemical, metallurgical, physical testing, and research.

> . . . [t]o satisfy the industry (whose demand is for maximum freedom from segregation, the utmost in soundness, the minimum amount and size of non-metallic inclusions, controlled grain size, and all the other modern requirements of quality steel) much has been learned, but a great deal still remains to be worked out. . . . The automotive engineer today designs his parts with full confidence that the steel specified, when properly treated, will have the desired physical properties--i.e., will do the work intended. This is the result of years of experience and cooperation with the steel maker. Present chemical and physical specifications have been the outgrowth of this experience."[16]

Some steel producing firms continued to argue that specifications were not the best way to promote better quality steel: for example, J. A. Mathews of Crucible Steel stated that

> . . . standard specifications usually are compromises and rarely are entirely satisfactory to either maker or user of the material. Ordinarily they do not result in furnishing the highest grade of material . . . . More recently certain specifications have required that the steel be a 'perfect steel.' Any material which can be manufactured commercially can with strict interpretation . . . be rejected, and this might easily happen on a falling market or on a long inventory.[17]

Even by the 1920s automakers were not completely satisfied with steel quality. In 1925 Walter Hildorf of Reo Motor Corporation asserted that the "main problem, at least for the present, is one of obtaining greater uniformity from heat to heat, rather than attempting to produce new steels"[18] and that there was need to continue to improve existing steels rather than to develop new steels. Automakers also complained about the same defects that had plagued rail consumers: seams, dirty steel, steel warpage, fractures, with no immediate solution in sight.

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[16] The Iron Age, November 1, 1928, p. 1092.

[17] The Iron Age, November 1, 1928, p. 1093.

[18] The Iron Age, November 19, 1925, p. 1378.

Steel producing firms were contending with new problems--raw materials of variable quality, high temperature production, and the telling fact that "present day metallurgy is so new that metallurgists do not agree on all specifications."[79] Hildorf acknowledged, however, that steel producers were making more progress than they had previously in addressing the concerns of their customers: "[s]everal of the steel companies are doing considerable work on this problem. It is hoped that they will continue their work."[80]

The need to produce automotive steels of consistent quality induced a few steel producing firms and one automaker to specialize in the production of automotive steel in the 1920s. As Iron Age reported in 1920 on Newton Steel's new mill, built to roll automobile sheets exclusively, it observed "[a] recent tendency in the sheet mill industry . . . toward the erection of plants devoted to the manufacture of automobile body sheets."[81] Michigan Steel built a similar automobile sheet plant in 1923 to produce automobile body, hood and fender sheets, and to treat special surfaces and body sheets for enameling.[82] Iron Age reported in 1923 on the laboratory of Wilson Foundry & Machine Company,[83] where the laboratory chief worked with the factory superintendent to "correlate all of the work, which results in more economical production, and much more harmonious operation of the

[79] The Iron Age, November 19, 1925, p. 1378.

[80] The Iron Age, November 26, 1925, p. 1449.

[81] The Iron Age, November 4, 1920, p. 1181.

[82] The Iron Age, January 3, 1924, p. 50.

[83] The Iron Age, July 26, 1923, p. 212.

plant."[14] All three firms were small steel producers, hoping to establish themselves in a specialty steel niche rather than to compete with the major steel producers.

One major automaker--Ford--integrated backward to steel production in 1922, erecting a small experimental steel plant, complete with electric furnaces and rolling mills.[15] In 1924 Ford added open-hearth furnaces, soaking pits, and additional electric furnaces;[16] as well, it equipped itself to produce steel directly from the ore, "not confining itself to any specific theories or methods, but (to) . . . follow leads which seem to have promise."[17] Iron Age was unconcerned about this encroachment of a major steel consumer into steel production: its editorial observed that

> it is to be hoped that the tentative plan of the Ford Motor Company to investigate the most meritorious processes for the production of steel direct from the ore may develop to the point of a thorough try-out.[18]

By 1925 Ford was rolling steel from purchased steel ingots and expected its open-hearth furnaces to come on line later that year.[19] Ford also experimented with electric steel production; after extensive experiments with its original two fifteen-ton Heroult furnaces, Ford considered

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[14]The Iron Age, July 26, 1923, p. 212.

[15]The Iron Age, November 30, 1922, p. 1441.

[16]The Iron Age, December 4, 1924, p. 1511.

[17]The Iron Age, January 10, 1924, p. 167.

[18]The Iron Age, January 10, 1924, p. 171.

[19]Ford had not yet completed backward integration into the production of steel ingots. See The Iron Age, December 10, 1925, p. 1633.

initiating its own duplexing process to produce steel in one continuous process from the blast furnaces to the mixers to the electric furnaces to the molds.[90] Later in 1925, Iron Age reported that Ford would eventually produce all of its own steel.[91]

By 1929 there were several new grades of auto steel, in marked contrast to 1900 when Bessemer steel was the primary steel available to automakers.[92] Iron Age naturally attributed much of the credit for achieving improved automotive steel to steel producers, and focused on cost-reducing rather than quality-increasing improvements: a 1925 editorial observed that

> [i]t can be said, indeed, that a better car at less money can be had today than was possible ten years ago . . . . the steel industry, in meeting that condition, has shown again that profits can be made as well through reduced costs as by raising prices.[93]

A chronicle of the history of automobile steel that contrasts to Iron Age's version was supplied by a noteworthy specialty steel supplier and steel innovator in the early twentieth century--American Rolling Mill, placing particular emphasis on incremental, cumulative improvements in automobile sheet steel:

> . . . [e]very five-year period since 1910 has shown a marked improvement in the quality of sheet steel produced for automobile purposes . . . .

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[90]The Iron Age, November 26, 1925, p. 1468.

[91]The Iron Age, February 26, 1925, p. 622.

[92]These included: auto-body grade of open-hearth steel, auto-body deep drawing grade also of open-hearth steel, auto-body extra deep-drawing grade of open-hearth steel, hood and fender grade, hood and fender deep drawing grade, hood and fender extra deep drawing grade, radiator casing grade. See The Iron Age, April 11, 1929, pp. 1006-08.

[93]The Iron Age, April 2, 1925, p. 986.

> In 1910 the general sheet steel requirements for automobiles were for full pickled, three-pass, cold-rolled and annealed flat sheets. These sheets were required to flat form around wooden frames for the bodies and to bead and double seam for the fenders.
>
> By 1915 special grades of auto-body sheets were ordered, to make cold-pressed metal stampings. These stampings, after much bumping, grinding, and hand hammering, were assembled to wooden frames. . . . Also, special grades of hood and fender sheets were ordered to serve the requirements of three and four coats of dipped enameling, with hand rubbing between coats.
>
> By 1920 cold-rolled strip mills had so widened their strip output as to give a new character of supply for crown fender work and to permit the fenders to be adaptable for two-coat dipped enameling without rubbing. . . .
>
> By 1925 a method of loose sheet rolling came into general use, which permitted the production of auto-body sheets practically equal to the standard of the hood and fender grades of former years. Also, all mills had greatly increased the extent of the range of drawing grades, and correspondingly the use of normalized sheets became greatly increased.
>
> Since 1925 a new trend has developed toward using sheets as wide as 63 in., whereas prior to 1925 the maximum obtainable was about 48 in. in width. This trend has permitted the automobile manufacturer to make larger but fewer stampings.
>
> Dovetailing with the recent process of lacquer finishing bodies, the constantly improving art of steel making has permitted the production of finer automobiles at extremely low cost.[14]

d. Alloy Steels

The expansion of the automotive industry helped to stimulate the development of alloy steels. Use of alloys spread throughout various steel-consuming industries concerned with obtaining quality and diversity in steel products. Even though alloy steels had long appeared to promise better quality steel, early on, the greater expense and the

[14] The Iron Age, April 11, 1929, p. 1006.

diversity of alloy steels hindered research on the part of both steel producing and consuming firms. As well, Iron Age hinted in 1909 that steel producing firms remained skeptical about alloy steels serving as a panacea to all steel problems:

> . . . of making many alloys there is no end and much study of them is a weariness to the flesh and small profit to the maker. It is hardly necessary at this late day that an article upon this subject should consist of long tables of remarkable physical tests . . . . Too often in the past such data have raised bright hopes in the mind of a steel consuming public, and too often results in practice have fallen short of published data.[55]

Over the next decade, steel producing and consuming firms began to compile a body of scientific information about alloy steels. Yet steel-producing interests lagged in this area of research also. A few steel producing firms experimented with alloy steels as a possible solution to rail breakages in the 1900s (See Chapters 3 and 4 regarding some early efforts by rail consumers to investigate alloy steel rails). In 1908 Passaic Steel successfully rolled manganese steel rails; initial tests showed that these rails had a high degree of tensile strength and elasticity.[56] In 1909 Pennsylvania Steel reported on its experiments with rolled manganese, or Manard, rails: this was considered to a significant advance because their previous experiments with manganese had involved the costly cast rails; however, for rolled manganese rails to be a commercial possibility, an economical method of rolling rails, special rolls, new rolling methods and more uniform chemical

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[55]The Iron Age, January 7, 1909, p. 24.

[56]Passaic had previously been unsuccessful in its attempts to roll such rails. See The Iron Age, September 10, 1908, p. 707.

compositions would all be needed.[97] Experiments with manganese rails continued throughout the 1910s with a number of elevated railway companies placing manganese rails in track; by 1918 Iron Age reported that five years of experimentation had shown manganese rails to have slower abrasion than ordinary steel rails.[98]

Other early alloying elements considered to be potential solutions to defective rails included vanadium and titanium.[99] George Auchy, a noted metallurgist, announced that vanadium was a potential alloying element in 1909; his tests had indicated that vanadium was superior to nickel in many respects but he believed that more research was needed.[100] Titanium Alloy Manufacturing Company announced in Iron Age in 1911 that it had solved the rail problem, offering as evidence the fact that, to date the New York Central, Lehigh Valley, Lackawanna, St. Paul, B&O, and Burlington Railroads had all used titanium rails and found them satisfactory.[101] A 1913 update by Titanium observed that

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[97]The Iron Age, April 22, 1909, pp. 1261-62. A previous experiment with cast manganese steel rails by the Boston Elevated Railway Company in 1908 indicated that manganese rails had great resistance. Rolling rails had not yet been successful; "the difficulties attending the rolling of manganese rails on a commercial scale were not small, the metal being extraordinarily hard at the proper rolling temperature."

[98]The Iron Age, February 28, 1918, p. 560. However, manganese rail heads seemed to spread and droop more easily.

[99]Tools were also an early field for experimentation with steel alloys. C. M. Bigger, a salesperson for Vanadium Steel Alloys Company, a manufacturer of alloy steels for tools, noted in 1913 that over the past ten years, numerous alloy steels--including nickel, nickel-chrome, nickel-vanadium, chrome, chrome-vanadium, vanadium, tungsten, and tungsten-vanadium--had all been developed for tools, manufactured by means of the open-hearth process. The Iron Age, March 20, 1913, p. 707.

[100]The Iron Age, January 21, 1909, p. 238.

[101]The Iron Age, September 7, 1911, p. 507.

titanium rails demonstrated such desirable characteristics as good ductility, endurance, and impact resistance.[102] In 1914 Iron Age praised the experimental rails of the American Vanadium Company, and noted the results that the wear from vanadium rails was about half that of ordinary carbon rails.[103]

Although these early experiments with alloy steel rails showed promise, rails were declining in demand. As of 1909 there were three principal uses for alloy material: alloys used for "materials of war,"[104] alloys used for tools, and alloys used for materials of construction. This last group received the most attention during the next decade, especially the automobile alloy steels--nickel steels, chrome nickel steels, and chrome vanadium steels:[105] as R. B. Abbott of Peerless Motor Car

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[102] The Iron Age, November 27, 1913, p. 1209.

[103] The Iron Age, October 15, 1914, p. 887.

[104] These were mainly nickel and tungsten alloys--"the makers of these alloys also conduct the heat treatments and guard their methods jealously." See The Iron Age, January 7, 1909, p. 25.

[105] Nickel steels were particularly difficult to produce without flaws, however; and the reputation of this alloy was weakened because of the early lack of metallurgical knowledge about nickel alloy; in an Iron Age article on the topic of articles: ". . . [t]his difficulty has been greater than need be because certain steel companies have mistaken a quality proposition for a tonnage proposition, and have offered nickel steel at absurdly low prices, wholly inconsistent with uniformity of analysis, careful workmanship and inspection. Discriminating users recognize this fact and are willing to pay a premium for the product of certain mills, because their steels are made in smaller tonnages and units, are more carefully handled from start to finish, are worked under hammers rather than in blooming mills, are made from purer materials and carefully inspected when done. The best is none too good for constructing the vital parts of an automobile, and when a concern has secured the best that the market affords, it has but taken the first step in producing good parts. . . . It is money wasted to buy good alloys unless one is willing to study them sufficiently to know how to treat them and then to supply adequate facilities for so doing." See The Iron Age, January 7, 1909, p. 25.

reported in 1920, "[t]he use of alloy steels has developed coincidentally with the development of the automobile."[106]

Automobile alloys came into prominence in the 1910s because automakers became more insistent on experimenting with the unique performance characteristics of alloy steels. The growth in demand for alloy steels sparked an increase in alloy research by both steel consumers and producers. But such research did not keep pace with the use of alloys, and as a result, marvelous properties were attributed to certain alloys in some cases that were not necessarily borne out by industrial research.

Chrome was one of the earliest alloys to be used in the automobile industry, due both to its decorative effects and its durability.[107] In 1917 Iron Age reported on the prominence of chrome vanadium among the commercial alloy steels, due to "the extremely wide range of physical qualities which are capable of being developed from this metal by proper methods of heat treatment."[108] However, only recently had systematic efforts been undertaken to investigate the precise chemical and physical properties of chrome vanadium alloy steel. Moreover, only a few steel consuming firms were studying and using chrome vanadium:

> . . . [the] advantages secured by this alloying element were relatively unknown except to a favorite few who, through their own research work, acquired intimate knowledge of the

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[106]The Iron Age, October 28, 1920, p. 1110.

[107]The Iron Age, March 17, 1927, p. 773.

[108]The Iron Age, August 2, 1917, p. 266.

characteristics bestowed upon iron by addition of this alloy.[109]

Even less experimentation was conducted with other potentially useful alloys in these early decades of the twentieth century, and there was need for more systematic study of these other alloys as well. C. N. Dawe of Studebaker emphasized this point in his report on chrome- and nickel-molybdenum steels to the Society of Automotive Engineers in 1922:

> . . . [s]uch propaganda has been spread with reference to these steels, and so much has been written regarding the history, possibilities, sources of supply and physical properties obtained, that there are many consumers as well as manufacturers who are poking on in a doubtful yet open frame of mind, desiring to gain further information, particularly with reference to application.[110]

Studebaker had experimented with a relatively unknown alloy--molybdenum steel--in axles, gears, and pinions and had been pleasantly surprised by the results: there were no reported failures in automobile parts made of chrome-molybdenum steel; and it had been produced at lower cost and sold at a lower price than chrome-vanadium steel.[111]

By 1920, there were nine alloy steels in use in the automobile industry, but no one alloy steel was "markedly superior:"

> . . . . The use of a particular type of alloy steel is largely a matter of personal preference which is usually backed up by a very decided conviction that this type is far superior to any other steel.
>
> This conviction is usually the result of one of two causes: The user is more familiar with that type through personal experience of his own or of friends and, more or less extensive experiments have apparently convinced the user of the superiority of one steel. Frequently a part made of one type of steel does not give satisfaction in

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[109] The Iron Age, August 2, 1917, p. 266.

[110] The Iron Age, March 16, 1922, p. 724.

[111] The Iron Age, March 16, 1922, p. 727.

service and other steels are tried until one is found successful. In many cases the original steel would have proved satisfactory if the correct heat treatment had been applied. It is all too common a practice to compare the efficiency of different types of steel by applying the same heat treatment to all, and judging the steels by the results . . .

I venture to say that in a large majority of the cases where one standard alloy steel has been condemned and another substituted, it has been the fault of the treatment rather than the steel.[112]

In 1925 Iron Age reported on the increasing importance of alloy steels, and noted the three outstanding advantages of alloys: their broader range of tensile strength; their ease of heat treatment; and their general stability and uniformity.[113] By the end of the decade a wider variety of alloys were being used in automobiles; by 1928 the list included nickel steels, chromium-nickel steels, chromium-vanadium steels, silico-manganese steels, and manganese steels, with most of these made by the open-hearth process.[114]

Thus, by the 1920s, due to increased demand for quality steels possessing the precise and reliable performance characteristics that steel consuming firms demanded, alloys had become an important and expanding part of the steel industry. As Iron Age reported in 1922, alloy steels had "advanced in importance, until to-day they play an indispensable role in industry."[115] In 1909 181,000 tons of alloy steel

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[112]The steels in use at the time included: plain carbon, nickel, chrome-nickel, chrome-vanadium, chrome, manganese, silicon, molybdenum, and silicon-nickel. See The Iron Age, October 28, 1920, p. 1111.

[113]The Iron Age, March 5, 1925, pp. 685-87.

[114]The Iron Age, November 1, 1928, p. 1092.

[115]The Iron Age, September 28, 1922, p. 791.

were produced in the U.S.--less than one percent of total steel output; by 1922 809,000 tons of alloy steels were produced--up to 4.1 percent of total steel output.[116] A 1924 Iron Age editorial observed that more alloy steel had been used in 1923 than ever before;[117] by 1924 total alloy output was up to 2 million tons[118]--double that of 1922.

A 1925 Iron Age report noted the great strides of research into alloy steel, only hinting at the importance of steel consuming firms:

> . . . no doubt in a measure due to many series of systematic researches and the better understanding of a domain of science that is governed by the laws of physical chemistry. This new field of progress is so important because of the remarkable properties obtained. By the development of the use of alloy steels the engineer has been provided with material permitting progress as to design and utility, hitherto undreamed of. . . . In the manufacture of these steels new problems become opened up for the steel maker and a much more complicated set of reactions takes place than with ordinary carbon steels.[119]

But there was still little scientific information on such important aspects of alloy steels as temperature effects, chemical reactions, and equilibrium constants, and "it is to the pure scientist that the steel maker must look."[120]

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[116] The Iron Age, September 28, 1922, p. 791.

[117] In 1913 the ratio of total steel output to alloy steel was 44 to 1, but by 1923 this ratio had dropped to 21 to 1. See The Iron Age, September 11, 1924, p. 650.

[118] The Iron Age, September 9, 1926, p. 718.

[119] The Iron Age, August 13, 1925, p. 408.

[120] The Iron Age, August 13, 1925, p. 408.

Related technological developments assisted in the development of alloy steel. Electric furnaces and heat treatment,[121] though known, were relatively unimportant in steel production until 1912; since then the expansion of alloy steel output was enabled in part by electric furnace production and heat treatment, and promoted by yet another technical association that came to be prominent in industrial research, the American Society for Steel Treating:

> Two modern developments have made the alloy steel industry possible. Their importance cannot be exaggerated. The first is the electric furnace. Its introduction made possible the production of most of the ferroalloys without which the

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[121]Heat treatment had appeared to be a promising area for improvement of steel for some time; yet rule-of-thumb methods had to be replaced with scientific methods: "heat treatment is not to be a hit-or-miss affair, but must be conducted rationally and in an approved manner under the direction of a competent metallurgical engineer. For each heat of steel a separate treatment must be worked out." See The Iron Age, July 24, 1913. Iron Age reported in 1914 and 1915 on experiments by the Pennsylvania Railroad and the ASTM (February 26, 1914, p. 546, and July 1, 1915, p. 21).

Even by 1920 R. B. Abbott of Peerless Motor Car complained that "to date, little theoretical work had been devoted to investigating heat treatment, with more effort, and more resources, devoted to manufacturing various alloys, with the result that "[t]he demand for heat treatment of steel has been developed so rapidly that the supply of men with the practical experience and the fundamental knowledge of the underlying theories necessary for this work has not been available. The result has been that men, not fully equipped with this experience and knowledge, have been compelled to assume charge of metallurgical laboratories and heat-treating operations and produce physical properties in steel demanded by the particular product made by their employers. This has usually been an expensive operation because it entailed a great deal of experimental work which otherwise would not have been necessary." . . . In many cases the original steel would have proved satisfactory if the correct heat treatment had been applied. It is all too common a practice to compare the efficiency of different types of steel by applying the same heat treatment to all, and judging the steels by the results . . . I venture to say that in a large majority of the cases where one standard alloy steel has been condemned and another substituted, it has been the fault of the treatment rather than the steel." See The Iron Age, October 28, 1920, p. 1110-11.

By 1924 about 3.5 million tons of steel was heat-treated in the U.S.: See The Iron Age, September 9, 1926, p. 718.

> large variety of other steels could not well be made. The second is the broadening effect of the art of heat treatment into a science and the production of equipment suitable for its use. Most alloy steels are of little value until after they have been heat treated, and upon their heat treatment depends the degree of their superiority. No more convincing proof of the growth of the alloy industry can be pointed to than the expansion of the American Society for Steel Treating from a beginning only four years ago to one of the largest technical organizations in the country.[112]

And new markets for alloy steel were emerging. In 1924 Iron Age reported that even though the automobile industry had been the largest consumer of alloy steel to date, other industries were beginning to increase their consumption of alloy steels--locomotives, agricultural implements, aircraft, and mining equipment: "the next few years should witness striking progress with expanding use of alloy steels, especially those made by electric processes."[113] Toward the end of the decade the aircraft industry became a large consumer of alloy steels, prompting new research into metals and methods for aircraft production.[114]

Several special-purpose alloys were developed by steel consuming firms that were especially active in industrial research, perhaps required to put their own labs to work to compensate for the lack of proactive research done by steel producers. In 1923 Iron Age reported on a new alloy of iron and nickel, Permalloy, likely to be important for electrical work, developed by the research labs of AT&T and Western

[112] The Iron Age, September 28, 1922, p. 793.

[113] The Iron Age, September 11, 1924, p. 620.

[114] The Iron Age, March 8, 1928, p. 709.

Electric.[125] In 1925 Iron Age reported on a new corrosion-resistant alloy, Everdur, developed by du Pont for a specific du Pont application:

> when its diversified properties were recognized and tested, it was decided recently to expand its applications to the general field. The du Pont Company is making exhaustive tests for new fabrications and resistant possibilities.[126]

In 1925, W. E. Ruder of General Electric's research department reported on the firm's research into silicon steel, noting some favorable characteristics that had been identified by microscopical examination of the steel.[127] Westinghouse labs also performed a great deal of industrial research into alloy steel, and developed many new alloys for electrical uses.[128]

Iron Age reported in 1927 that industrial research had promoted much of the increased demand for alloy steels, citing the example of the

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[125]The metal had high permeability and was ideally suited for telephone and radio transformers. See The Iron Age, May 3, 1923, p. 1254.

[126]The Iron Age, February 5, 1925, p. 412.

[127]The Iron Age, June 4, 1925, p. 1634. In 1929 General Electric announced that it had developed a new short-cycle annealing process for the production of malleable iron castings which saved much time in the manufacturing process and yielded castings with higher tensile strength and yield points than other annealing procedures. The details of the procedure had been determined through General Electric's own foundry experimentation. Annealing was a process of particular interest to electrical manufacturers, as it helped produce steel that would give the lowest electrical losses. A 1929 Iron Age article on the General Electric process noted that, before the electrical furnace, magnetic steels used in electrical manufacturing were made in oil-fired furnaces, with "unsatisfactory results . . . (and) excessive cost." General Electric had found that the use of electrical furnaces in the annealing process yielded impressive cost savings as well as permitting greater ease of handling materials and improved quality of the output. See The Iron Age, September 19, 1929, p. 776; and October 17, 1929, p. 1037.

[128]Bartlett, "The Development of Industrial Research in the United States," p. 55.

industrial research lab of the Chrobaltic Tool Company. This lab had been established initially to study alloy materials for use in producing tools, and had expanded from this small beginning:

> the original purpose . . . was the scientific investigation of materials for present requirements as well as new metals for use in the engineering field. The possibilities of a more extended use in industry of alloy castings were such that it was decided to separate the research department from its parent organization and to make it a separate unit, which would carry on metallurgical investigations of alloys and develop a market for its products.[129]

Section 4. Conclusion--Diversification and Demystification of Steel Research

Iron Age reported in 1926 that steel products had become greatly diversified, due to technological developments with heat treated and alloy steels, and market incentives with the emergence of the automobile, electrical and communications industries. As a result, two major changes in steel production had come about. First, "means are being devised to make a pound of metal render more service:"[130] evidenced by the greater loads carried by steel rails and the greater amounts of electrical energy transmitted through steel wires. Second, a multitude of metals with special properties were being produced:

> since there are a number of non-ferrous metals available, it is not surprising that the latter should be found capable of fulfilling an increasing proportion of these special requirements.[131]

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[129]The Iron Age, April 14, 1927, p. 1065.

[130]The Iron Age, September 9, 1926, p. 718.

[131]The Iron Age, September 9, 1926, p. 718.

The engineers, chemists, and other technicians employed by steel producing and consuming firms, were increasingly devoting their efforts to studying the increased varieties of alloys and treated steels available, and to select the best steel for the job--heat-treated, alloy, or plain carbon, considering the cost, availability, shapes, and physical properties of all available steels:

> [a]ssuming that several materials will function suitably in service, the selection should be made on the basis of ultimate economy. This may be referred to as economic compromise. . . . the selection of the material is even more important from the standpoint of the quality of service to the consumer than it is in the direct manufacturing cost. Here the economic compromise must take into consideration that which will behave best in service.[132]

Industrial testing of materials had been an important aspect of the innovations in steel products and processes: in most modern factories an "enormous amount"[133] of testing was being conducted:

> . . . [t]he engineer of today is better able to approach the ideal economic compromise in the selection and use of material than was the engineer of yesterday.
>
> The engineer is confronted with a difficult talk [sic] in the adaptation and selection of metals for various uses, even with the metals and alloys now available. But metals and alloys with new and improved properties are currently being made available for his use. New processes for fabricating metals are being developed and old ones are being improved. Any such new material or process may disturb the economic balance. . . .
>
> The engineer's already difficult tasks are made even more difficult by a constant change in the state of the metal art. The progressive engineer should not only have a thorough understanding of services to which metals are to be put, but he should have also a general understanding of the principal properties of the metals and alloys.[134]

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[132] The Iron Age, September 9, 1926, p. 718.

[133] The Iron Age, September 9, 1926, p. 718.

[134] The Iron Age, September 9, 1926, pp. 718-19.

In 1927, Iron Age reported on the lab of a steel treater, Illingsworth Steel, and summed up the role of testing and specification-making in promoting the incremental, cumulative change in steel products and processes through interaction between steel consuming and producing firms: "[t]he laboratory can function as a part of routine when the cloak of mystification is removed, and the personnel revealed as willing to discuss their findings in understandable terms."[135]

[135] The Iron Age, February 17, 1927, p. 490.

CHAPTER 6

SUMMARY OF FINDINGS AND CONCLUSION

Section 1. Introduction

The U.S. steel industry between 1870 and 1930 has usually been described as relatively non-innovative. Yet there was considerable industrial research into steel products and processes underway on the part of steel consuming firms and technical associations. This industrial research into the manufacture and processing of steel occurred in a different fashion than that described in much of the literature on U.S. industrial research: a substantial amount of early industrial research was directed at developing a body of consistent scientific knowledge about the properties of existing products and processes rather than at developing new products and processes. This industrial research in steel was part of the crucial transition in American industry from rule-of-thumb methods to scientific methods.

As the preceding chapters have shown, this industrial research relied on interaction and cooperation between industrial research practitioners of steel consuming and steel producing firms, organized through loose interfirm arrangements and technical associations. From this alternative mode of industrial research derived cumulative and incremental technological changes in steel which yielded great economic benefits for steel consuming and steel producing firms alike.

Description of the alternative mode of industrial research that occurred in the manufacture and processing of steel between 1870 and 1930 is a useful addition to previous economic histories of American industrial research because it provides a different perspective on technological change in the early part of this century. Elements of the alternative model of industrial research that fit this process may prove to be a useful supplement to existing economic theories of technological change and industrial research that are applicable even in our own time.

Section 2. Summary of Findings

Applying the standard definition of industrial research to the U. S. steel industry would lead one to conclude that there was little industrial research in this industry between 1870 and 1930. Yet significant improvement in the manufacture and processing of steel did occur. An alternative model of industrial research was developed for use in this dissertation. This allowed use of a broader institutional context for the innovative process and for description of the kinds of incremental and cumulative improvements that occurred in existing steel products and processes over the six decades from 1870 to 1930.

Increased demand for Bessemer steel rails after the Civil War induced a series of incremental, cumulative, cost-reducing, output-increasing innovations in steel production. Organized in-house industrial research by steel producing firms did not play a large part in these innovations; rather, these innovations were developed primarily through the efforts of "rule-of-thumb" persons. But, toward the end of the nineteenth century, some steel producing firms began to recognize the importance of implementing scientific methods and began to hire trained chemists and metallurgists, primarily to test the iron ores that were the inputs into the steel production process.

Testing of inputs--the primary activity of steel industry chemists and metallurgists--did not produce sufficient improvement in the quality of steel products and processes for many steel consuming firms. A number of industrial research labs were established by steel consuming firms to investigate steel products used by their firms. One steel consuming firm, the Pennsylvania Railroad, began to study steel and, in so doing, induced industrial research on the part of some producing firms. Specification-making and material testing improved the quality of materials used by the Pennsylvania Railroad and yielded tremendous economic benefits for the railroad. In the case of steel products, the interactive process between this steel consumer and many of its steel suppliers fostered the development of a body of scientific knowledge about steel as well as the later exploitation of that knowledge for industrial purposes.

A novel institutional framework that brought together producers and consumers of commercial engineering materials--the American Society for Testing Materials (ASTM)--was established as well during these decades. This was necessary because in the first decade of the twentieth century steel producers argued that specifications drawn up by steel consumers, who typically were not actively engaged in steel production, lacked essential practical knowledge about steel production. The ASTM facilitated communication between steel consumers and steel producers about the desired properties in steel used by steel consuming firms and about the technical and pecuniary difficulties of these desired improvements. As with the Pennsylvania Railroad, much of the early attention of the ASTM was directed toward steel products. The ASTM helped to stimulate establishment of in-house industrial research labs on the part of both steel producing and consuming firms by the 1920s.

Although stable oligopoly in the steel industry provided little incentive for major innovations on the part of leading steel firms, major shifts in the nature and quality of the steel products demanded by steel consumers continued to induce a series of incremental and cumulative innovations on the part of steel producers well into the 1920s. Steel consuming firms--especially manufacturers of automobiles and electrical equipment--continued to play a strong role in promoting industrial research in steel. The demands by these new steel consumers for specialty alloy steels and precise performance characteristics coincided with the beginning of the transition from rule-of-thumb to science in steel producing firms that was initiated by the railroads, and, in so doing, the extent of industrial research by steel producing firms increased by the 1920s.

Section 3. Conclusion

As observed in Chapter 1, little systematic research has been done on the pre-World War I era of industrial research. Yet this was a period of substantial industrial research. This early industrial research, to the extent it has been described at all, has been characterized by the feats of famous industrial research pioneers--General Electric, AT&T, and du Pont--who established in-house industrial research laboratories to maintain their market positions in technologically advanced industries. There are important lessons to be gained from examining the economic history of industrial research at these prominent innovating firms. First, these industrial research pioneers represented a "significant departure from previous days when invention was mainly the work of independent inventors."[1] Second, each of these firms had previously used mergers to control price and output in their respective industries. With the threat of antitrust prosecution and of hostile public opinion, these firms turned to in-house industrial research as an effective means of non-price competition.[2] Third, successful in-house industrial research provided these firms the means to compete in environments of rapid technological change. Industrial research was directed both at controlling technologies of short-term commercial concern and at positioning these firms for long-term corporate survival in technologically-advancing industries. Finally, the success of industrial research efforts on the part of these famous industrial research pioneers helped to promote the spread of industrial research after the first world war and in the later twentieth century.[3]

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[1]Mansfield, The Economics of Technological Change, p. 44.

[2]Janet Knoedler, "As Much Technological as Pecuniary: Turn-of-the-Century Combinations in Three Major Industries," Journal of Economic Issues XXIV (June 1990), pp. 397-404.

[3]As Reich argues, the National Research Council began a major effort to "proselytize for scientific-industrial research" after the first world war, and frequently held up General Electric and AT&T as examples of successful in-house industrial research; as well, prominent industrial research representatives for those two firms helped to

However, it may be that the prominence given to these firms and these industries has excessively narrowed the economist's view of the process of industrial research. The most intense focus has been on a model where firms choose to move into industrial research as part of a strategy of non-price competition in which the development of revolutionary new products and processes will protect, or increase, the firm's market share.

Due to the paucity of statistical data, there have been few attempts to examine, in broader perspective, the early history of industrial research in the U.S., and thus there has been little evidence to alter the view that this was the sole reason for industrial research. The one general study undertaken that utilizes available pre-World War II data supports the view that industrial research was closely related to changes in firm strategies and market conditions. Thus the typical view, that industrial research is a firm-level strategy undertaken by large firms to protect market share, or by smaller firms seeking to attain the status of large firms, is reinforced.[4]

Yet we have seen that this is an incomplete version of the early history of industrial research. In-house industrial research laboratories were established by many firms between 1870 and 1930; and, in accordance with the major thesis of this dissertation, there was

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promote the work of the National Research Council. See The Making of American Industrial Research, p. 254. Galambos adds that a "fundamental shift in managerial attitudes" after the first world war helped to increase the extent of industrial research. See "The American Economy and the Reorganization of the Sources of Knowledge," p. 278.

[4]Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing, 1899-1945."

significant industrial research, though of a different sort than that which occurred in the labs of the famous industrial research pioneers between 1870 and 1930. This alternate mode of early industrial research was directed, not at developing revolutionary new products and processes as were those of the industrial research labs of G. E. and AT&T, but, rather, at developing a body of consistent scientific knowledge about existing products and processes.

In this dissertation, industrial testing has been considered an important industrial research activity. Testing was an important part of learning by using and was critical to the process of diffusion of technological improvements of steel products and processes. Moreover, testing helped to identify useful technological directions for incremental improvements for steel products and processes and to establish the underlying science of the existing technology. In the cases described above, where consuming firms and technical associations like the Pennsylvania Railroad and the ASTM determined, through testing, precise physical and chemical requirements for products, producing firms were consequently induced to establish industrial research in order to produce output of sufficient quality to meet users' requirements.

Industrial testing enabled compilation of the first systematically collected body of scientific information on industrial materials by industrial testing scientists. This information was obtained both in the line of routine research work and through special investigations. This was an important contribution to industrial technology, even if it was not a new scientific advance. As observed in Chapter 5, many steel producing firms that did not have official industrial research labs did in fact have ongoing testing activities underway under the auspices of the ASTM. And many early industrial research labs that were established to handle the presumably routine, day-to-day functions of testing and analysis moved into longer-range studies. In short, the observable industrial research activity in the early twentieth century consisted largely of testing.

The cooperative nature of research in steel is as much overlooked as is the importance of testing. Consuming firms like the Pennsylvania Railroad worked with producing firms in testing products and materials and in developing specifications, in the process, undertaking substantial cooperative industrial research. Technical associations like the ASTM sponsored a great deal of interfirm industrial research into a wide variety of industrial materials. Both the Pennsylvania Railroad and the ASTM created diverse and complex institutional arrangements for cooperative industrial research, and helped to promote other institutions that helped to share, and thus diffuse, technological information regarding improvements in steel products and processes.

The alternative view of industrial research described in Chapter 1 above is greatly superior in its fit to the reality of the processes of industrial research in steel in the U. S. between 1870 and 1930. The industrial research process was multidirectional; diffusion helped promote further incremental innovation in products and processes; incremental improvements produced important economic gains; consuming firms were able to induce technological directions in the innovative work of producing firms; testing was an important aspect of a multidirectional, incremental industrial research process and helped to induce a fundamental transition during these early decades in many industries from older "rule-of-thumb" industrial procedures to newer and ultimately more reliable science-based industrial methods; and the process relied upon close interaction between consuming firms and producing firms.

This dissertation provides evidence that the alternative view of industrial research summarized here is a superior one for the description of past industrial research efforts in steel products and processes. It seems probable that further application of this model will yield richer description of such research in the present as well. Given the recent discussion of cooperative industrial research and the technology gap between the U. S. and other major industrialized competitor nations, more attention is being directed to cooperative industrial research arrangements used by Japanese and German industry. Many historical precedents for cooperative industrial research have been overlooked; the efficacy of these historical instances of cooperative industrial research may bear on the current debate.

BIBLIOGRAPHY

Primary Sources

American Railway Engineering Association. Proceedings. Various volumes, 1900-1920.

American Rolling Mill Company. Consider the Tack. Middletown, Ohio: American Rolling Mill Company, 1936.

American Rolling Mill Company. The First Twenty Years. Middletown, Ohio: American Rolling Mill Company, 1922.

American Rolling Mill Company. Methods for the Analysis of Iron and Steel, Used in the Laboratories of the American Rolling Mill Company. Middletown, Ohio: American Rolling Mill Company, 1912.

American Rolling Mill Company. Research and Methods of Analysis of Iron and Steel at Armco. Middletown, Ohio: American Rolling Mill Company, 1920.

American Society for Testing Materials. Proceedings. 1902-1930.

American Society for Testing Materials. Yearbook. 1910, 1920, 1925.

Iron Age. 1901-1930, various issues.

Pennsylvania Railroad Archives. Hagley Museum and Library, Wilmington, Delaware. Accession 1810.

Secondary Sources

Abernathy, W. and Clark, K. "Innovation--Mapping the Winds of Creative Destruction." Research Policy 14: 3-22.

Abernathy, William J. and Utterback, James M. "Patterns of Industrial Innovation." Technology Review (June/July 1978): 41-47.

Adams, Walter. "The Steel Industry." In Adams, ed., The Structure of American Industry. New York: The MacMillan Company, 1954.

Alchian, A. and Demsetz, H. "Production, Information Costs, and Economic Organization." American Economic Review (December 1972):

Allen, J.A. Studies in Innovation in the Steel and Chemical Industries. Manchester, Great Britain: Manchester University Press, 1967.

Ames, Edward. "Research, Invention, Development, and Innovation." American Economic Review 51 (1961): 310-18.

American Institute of Chemical Engineers (Kirkpatrick, S. D., ed.). Twenty-five Years of Chemical Engineering Progress. New York: D. Van Nostrand, 1933.

Angell, J. R. "The Development of Research in the United States." Washington, D. C.: National Research Council, Reprint and Circular Series, no. 6, 1919.

Arrow, Kenneth. "Economic Welfare and the Allocation of Resources for Invention," in Nathan Rosenberg, ed., The Economics of Technological Change. Middlesex, England: Penguin Books, Ltd., 1971.

Bain, Joe S. Barriers to New Competition. Cambridge, Massachusetts: Harvard University Press, 1956.

Baldwin, William L. Market Power, Competition, and Antitrust Policy Homewood, Illinois: Richard D. Irwin, Inc., 1987.

Baldwin, W. L. and Childs, G. L. "The fast second and rivalry in research and development." Southern Economic Journal 35: 18-24.

Bartlett, Howard R. "The Development of Industrial Research in the United States." In National Research Council, Research--A National Resource, Vol. II. Washington, D. C.: U. S. Government Printing Office, 1940.

Bass, L. W. "Historical Development of Industrial Research in the United States." Chemistry and Industry (June 9, 1962): 1000-03.

Bates, Ralph S. Scientific Societies in the United States. Cambridge, Massachuestts: MIT Press, 1965.

Battelle Memorial Institute. Research at Battelle Memorial Institute, the First Thirty Years. Battelle Memorial Institute, 1960.

Beers, John J. and Lewis, W. D. "Aspects of the Professionalization of Science." Daedalus (Fall 1963): 764-84.

Berg, Sanford V. et al. Joint Venture Strategies and Corporate Innovation. Cambridge, Massachusetts: Oelgeschlager, Gunn & Hain, Publishers, Inc., 1982.

Berglund, Abraham. The United States Steel Corporation. New York: Columbia University Press, 1907.

Berglund, Abraham. "The United States Steel Corporation and Price Stabilization," Quarterly Journal of Economics, November 1923.

Berglund, Abraham. "The United States Steel Corporation and Industrial Stablization." Quarterly Journal of Economics (August 1924):

Bernal, J. D. Science and Industry in the Nineteenth Century. London: Routledge & Kegan Paul, 1953.

Bichowsky, F. Russell. Industrial Research. Brooklyn, New York: Chemical Publishing Company, 1942.

Birr, Kendall. "Industrial Research Laboratories." In Reingold, ed., The Sciences in the American Context. Washington, D. C.; 1979.

Birr, Kendall. Pioneering in Industrial Research: The Story of the General Electric Research Laboratory. Washington, D.C.: Public Affairs Press, 1957.

Birr, Kendall. "Science in American Industry," in David Van Tassel and Michael G. Hall, eds., Science and Society in the United States. Homewood, Illinois: The Dorsey Press, 1966.

Borth, Christy. True Steel. Indianapolis: Bobbs-Merrill, 1941.

Brozen, Yale. "Trends in Industrial Research and Development." Journal of Business (July 1960):

Cahan, David. "Werner Siemens and the Origin of the Physikalische-Technische Reichsanstalt, 1872-1887." Historical Studies in the Physical Sciences 12 (1982):

Campbell, Harry H. The Manufacture and Properties of Iron and Steel. New York: The Engineering and Mining Journal, 1903.

Carnegie, Andrew. The Autobiography of Andrew Carnegie. Boston: Houghton, 1920.

Caves, Richard. "Industrial Organization, Corporate Strategy, and Structure." Journal of Economic Literature XVIII, # 2 (March 1986):

Chandler, Alfred. "From Industrial Laboratories to Departments of Research and Development," in Kim B. Clark et al, The Uneasy Alliances. Boston: Harvard Business School Press, 1985.

Chandler, Alfred D., Jr. Scale and Scope: The Dynamics of Industrial Capitalism. Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 1990.

Chandler, Alfred D., Jr. Strategy and Structure: Chapters in the History of the Industrial Enterprise. Garden City, NY: Anchor Books, Doubleday & Co., Inc., 1966.

Chandler, Alfred D., Jr. The Visible Hand. Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 1977.

Clark, John Maurice. Competition as a Dynamic Force. Washington, D.C.: The Brookings Institution, 1961.

Clark, John Maurice. Studies in the Economics of Overhead Costs. Chicago: The University of Chicago Press, 1923.

Clark, Victor S. History of Manufactures in the United States, 3 vols. New York: Peter Smith, 1949.

Clemence, Richard V. and Doody, Francis S. The Schumpeterian System. New York: Augustus M. Kelley, Bookseller, 1963.

Clow, Archibald. The Chemical Revolution. London: Batchworth Press, 1952.

Coase, R. H. The Firm, the Market and the Law. Chicago: The University of Chicago Press, 1988.

Cochrane, Rexmond C. Measures for Progress, A History of the National Bureau of Standards. Washington, D. C.: National Bureau of Standards, U. S. Department of Commerce, 1966.

Comanor, W. S. "Research and Technological Change in the Pharmaceutical Industry." RESTAT 47: 182-90.

Comanor, W. S. "Market Structure, Product Differentiation and Industrial Research." Quarterly Journal of Economics 81: 645-52.

Coolidge, W. D. "Organized Industrial Research." Science 79: 130.

Dasgupta, P. and Stiglitz, J. "Uncertainty, industrial structure, and the speed of R&D." Bell Journal of Economics 11, # 1 (Spring 1980): 1-27.

Daugherty, Carroll, R., de Chazeau, Melvin G., and Stratton, Samuel S. The Economics of the Iron and Steel Industry, 2 vols. New York: Published for Bureau of Business Research, University of Pittsburgh by McGraw-Hill Book Co., Inc., 1937.

David, Paul. Technical Choice, Innovation, and Economic Growth. Cambridge: Cambridge University Press, 1975.

Davis, Harvey, and Davies, C. E., "Industrial Research by Mechanical Engineers," in National Research Council, Research--A National Resource, vol. II. Washington, D. C.: National Research Council, 1940.

Dennison, S. R. "Vertical Integration and the Iron and Steel Industry." Economic Journal XLIX (June 1939):

Dosi, Giovanni. "The nature of the innovative process," in Dosi et al, Technical Change and Economic Theory. London: Pinter Publishers, 1988.

Dosi, Giovanni, "Technological paradigms and technological trajectories," Research Policy, 1982.

Dosi, Giovanni et al. Technical Change and Economic Theory. London: Pinter Publishers, 1988.

Durfee, W. F. "The First Chemical Laboratory." Bulletin, American Iron and Steel Association 30 (November 10, 1896): 249.

Durfee, W. F. "The Manufacture of Steel." Popular Science Monthly 39 (October 1891): 729-49.

Durfee, W. F. "The Manufacture of Steel, Continued." Popular Science Monthly 40 (November 1891): 15-40.

Edwards, Richard. "Stages in Corporate Stability and the Risks of Corporate Failure." Journal of Economic History XXXV (June 1975): 428-57.

Fellner, William. Competition among the Few. New York: Alfred A. Knopf, 1949.

Fellner, W. J. "The Influence of Market Structure on Technological Progress." Quarterly Journal of Economics 65 (1951): 650-67.

Fisher, Douglas Alan. The Epic of Steel. New York: Harper and Row: 1963.

Fisher, Franklin and Temin, Peter, "Returns to Scale in Research and Development: What Does the Schumpeterian Hypothesis Imply?" Journal of Political Economy, 1981.

Fleming, Arthur Percy Morris. Industrial Research in the United States of America. London: Published for the Department of Scientific and Industrial Research, by His Majesty's Stationery Office, 1917.

Freeman, Christopher. The Economics of Industrial Innovation. Cambridge, Massachusetts: The MIT Press, 1982.

Freeman, Christopher. Unemployment and Technical Innovation. London: Frances Pinter, 1982.

Furnas, C. C. Research in Industry. Princeton, New Jersey: D. Van Nostrand Co., Inc., 1948.

Galambos, Louis. "The American Economy and the Reorganization of the Sources of Knowledge." In Oleson and Voss, The Organization of Knowledge in Modern America, 1860-1920. Baltimore: The Johns Hopkins University Press, 1979.

Galambos, Louis. "The Emerging Organizational Synthesis in Modern American History," Business History Review, Autumn 1970.

Gilfillan, S. C. The Sociology of Invention. Cambridge, Massachusetts: MIT Press, 1970.

Goodale, Stephen L. Chronology of Iron and Steel. Pittsburgh: Pittsburgh Iron and Steel Foundries Company, 1920.

Gort, Michael. Diversification and Integration in American Industry. Princeton, NJ: Princeton University Press, 1962.

Grabowski, H. G. "The Determinants of Industrial Research and Development: A Study of the Chemical, Drug, and Petroleum Industries." Journal of Political Economy 76: 292-306.

Greene, A. M. "Conditions of Research in U. S." Mechanical Engineering (July 1919): 588.

Habbakuk, H. J. American and British Technology in the Nineteenth Century. Cambridge: Cambridge at the University Press, 1962.

Hamberg, D., "Invention in the Industrial Research Policy," The Journal of Political Economy, April 1963.

Hamberg, D. R&D: Essays on the Economics of Research and Development. New York: Random House, 1963.

Hall, William Thomas. The Chemical and Metallographic Examination of Iron, Steel, and Brass. New York: McGraw-Hill Book Co., 1921.

Hamberg, D. "Invention in the industrial research laboratory." Journal of Political Economy 71: 91-115.

Harris, Christopher and Vickers, John. "Patent Races and the Persistence of Monopoly." Journal of Industrial Economics (June 1985): 461-88.

Hertz, David. The Theory and Practice of Industrial Research. New York: McGraw-Hill, 1950.

Hibbard, Henry D. Manufacture and Uses of Alloy Steel. Washington, D. C.: Government Printing Office, 1916.

Hogan, William T. Economic History of the Iron and Steel Industry in the U. S. Lexington, Massachusetts: Lexington-D. C. Heath, 1971.

Holland, Maurice. Industrial Explorers. New York: Harper & Bros., Publ., 1929.

Holland, Maurice, and Spraragen, W. Research in Hard Times. Washington, D. C.: Division of Engineering and Industrial Research, National Research Council, 1940.

Horowitz, I. "Firm Size and Research Activity." Southern Economic Journal 28: 298-301.

Houghton, E. F. Steel and Its Treatment. Philadelphia: E. F. Houghton & Co., 1918.

Hounshell, David A. and John Kenly Smith, Jr. Science and Corporate Strategy, DuPont R&D, 1902-1980. Cambridge: Cambridge University Press, 1988.

Howe, Henry M. Iron, Steel and Other Alloys. Boston: Sauveur and Whiting, 1903.

Hungerford, Edward. The American Railroad in Laboratory. Washington, D. C.: American Railway Association, 1933.

Jenkins, Reese. Image and Enterprise: Technology and the American Photographic Industry, 1839-1925. Baltimore: The Johns Hopkins University Press, 1975.

Jerome, Harry. Mechanization in Industry. New York: NBER, 1934.

Jewett, Frank. "Industrial Research: What It Is, Its Place in Modern Industrial Technology, the Opportunities It Offers." Frank A. Howard Lecture, February 11, 1948.

Jewett, Frank. "Industrial Research," National Research Council, Reprint and Circular Series of the National Research Council, No. 4, p. 15.

Jewkes, John et al. The Sources of Invention. New York: W.W. Norton & Co., 1969.

Job, Robert. "Steel Rails: Relations between Structure and Durability." Journal of the Franklin Institute (July-August 1902):

Jones, Eliot. "Is Competition in Industry Ruinous?" Quarterly Journal of Economics, XXXIV, May 1920, pp. 423-58.

Jorde, Thomas and Teece, David. "Innovation and Cooperation: Implications for Competition and Antitrust." Journal of Economic Perspectives, Summer 1990.

Kahn, E. J., Jr. The Problem Solvers: A History of Arthur D. Little, Inc. Boston: Little, Brown, and Co., 1986.

Kamien, Morton I. and Nancy L. Schwartz. Market Structure and Innovation. Cambridge: Cambridge University Press, 1982.

Kamien, Morton I. and Schwartz, Nancy L. "Market structure and innovation: a survey." Journal of Economic Literature 13, # 1 (1975): 1-37.

Kamien, Morton I. and Nancy L. Schwartz. "Market Structure, Rival's Response, and the Firm's Rate of Product Improvement." Journal of Industrial Economics XX: 159-72.

Kaplan, A. D. H. Big Business in a Competitive System. Washington, D.C.: The Brookings Institution, 1964.

Katz, Michael L. "An analysis of cooperative research and development," Rand Journal of Economics, Winter 1986.

Kay, Neil. The Innovating Firm: A Behavioral Theory of Corporate R&D. New York: St. Martin's Press, 1979.

Kline, Stephen J., and Nathan Rosenberg. "An Overview of Innovation," in Ralph Landau and Nathan Rosenberg, eds., The Positive Sum Strategy. Washington, D. C.: National Academy Press, 1986.

Knoedler, Janet. "As Much Technological as Pecuniary: Turn-of-the Century Combinations in Three Major Industries," Journal of Economic Issues, June 1990, pp. 397-404.

Knoedler, Janet. "The American Railway Engineering Association and Improvement in Steel Rails." Unpublished manuscript. 1990.

Kuznets, Simon. "Inventive Activity: Problems of Definition and Measurement." In The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton: Princeton University Press, 1962.

Lamoreaux, Naomi. The Great Merger Movement in American Business, 1895-1904. Cambridge: Cambridge University Press, 1985.

Landes, David S. The Unbound Prometheus. Cambridge: Cambridge University Press, 1969.

Lewis, W. D. "Industrial Research and Development." In Kranzberg and Pursell, eds., Technology and Western Civilization. Oxford: Oxford University Press, 1967.

Little, Arthur D. "Organization of Industrial Research." American Society for Testing Materials, Topical Discussion on Cooperation in Industrial Research. Philadelphia: American Society for Testing Materials, 1918.

Livermore, Shaw, "The Success of Industrial Mergers," Quarterly Journal of Economics 50 (1936), pp. 68-96.

Livesay, Harold. Andrew Carnegie and the Rise of Big Business. Baltimore: Little, Brown, and Co., 1975.

Livesay, Harold C. and Porter, Patrick G. "Oligopolists in American Manufacturing and their Products." In McGraw, ed., The Essential Alfred Chandler. Boston: Harvard Business School Press, 1988.

Livesay, Harold C. and Porter, Patrick G. "Vertical Integration in American Manufacturing, 1899-1948." Journal of Economic History XXIX (September 1969): 494-500.

Lundvall, Bengt-Ake. "Innovation as an interactive process: from user-producer interaction to the national system of innovation," in Dosi et al, eds., Technical Change and Economic Theory. London: Pinter Publishers, 1988.

Lynch, David. The Concentration of Economic Power. New York: Columbia University Press, 1946.

MacDowell, Charles. "The Chemist in the Packing and Allied Industries." Chemical Age (June 1921): 217-20.

MacLaurin, W. Rupert. Invention and Innovation in the Radio Industry. New York: The MacMillan Co., 1949.

MacLaurin, W. Rupert. "The Process of Technological Innovation: The Launching of a New Scientific Industry." American Economic Review 60: 90-112.

MacLaurin, W. Rupert. "Technical Progress in Some American Industries." American Economic Review (May 1954):

Mansfield, Edwin. The Economics of Technological Change. New York: W. W. Norton & Co., Inc., 1968.

Mansfield, Edwin. "Entry, Innovation, and the Growth of Firms." American Economic Review (December 1962): 1024-26.

Mansfield, Edwin. Industrial Research and Technological Innovation. New York: W. W. Norton, 1968.

Mansfield, Edwin et al. The Production and Application of New Industrial Technology New York: W. W. Norton & Co., Inc., 1977.

Mansfield, Edwin et al. Research and Innovation in the Modern Corporation. New York: W. W. Norton & Co., Inc., 1971.

Mansfield, Edwin. "Size of Firm, Market Structure, and Innovation." Journal of Political Economy (Dec. 1963):

Mansfield, Edwin, et al. "Social and Private Rates of Return from Industrial Innovations." Quarterly Journal of Economics 91 (May 1977): 221-40.

Mansfield, Edwin. "Technical Change and the Rate of Imitation." Econometrica. October 1961:

Mansfield, Edwin. "Technical Change and the Rate of Imitation." In Rosenberg, Nathan, The Economics of Technological Change. Middlesex, England: Penguin Books, Ltd., 1971.

Markham, Jesse, "Economic Analysis and the Research and Development Decision," in Richard A. Tybout, Economics of Research and Development. Ohio State University Press, 1965.

Markham, J. W. "Market Structure, Business Conduct and Innovation." American Economic Review (May 1965): .

Marris, Robin and Dennis C. Mueller. "The Corporation, Competition, and the Invisible Hand." Journal of Economic Literature (March 1980): 32-63.

Mason, Edward. "Schumpeter on Monopoly and the Large Firm." RESTAT XXXIII (May 1951): 139-44.

Mayhew, Anne. "Schumpeterian Capitalism versus the 'Schumpeterian Thesis,'" Journal of Economic Issues, June, 1980, p. 583.

McGraw, Thomas, ed. The Essential Alfred Chandler: Essays toward a Historical Theory of Big Business. Boston: Harvard Business School, 1988.

McNulty, Paul J. "On Firm Size and Innovation in the Schumpeterian System." Journal of Economic Issues 8, # 3 (1974): 727-32.

Meade, Edward Sherwood. "The genesis of the United States Steel corporation." Quarterly Journal of Economics XV (August 1901): 517-50.

Mees, C. E. Kenneth, and John A. Leermaker. The Organization of Industrial Scientific Research. New York: McGraw-Hill Book Co., Inc., 1950.

Mowery, David Charles. The Emergence and Growth of Industrial Research in American Manufacturing, 1899-1945. Ph.D. dissertation, Stanford University, 1981.

Mowery, David C. "Firm Structure, Government Policy, and the Organization of Industrial Research: Great Britain and the United States, 1900-1950." Business History Review 58, # 4 (Winter 1984): 504-531.

Mowery, David C. "Industrial Research and Firm Size, Survival, and Growth in American Manufacturing, 1921-1946: An Assessment." Journal of Economic History 43, # 4 (1983): 953-980.

Mowery, David C. "The Relationship between Intrafirm and Contractual Forms of Industrial Research in American Manufacturing, 1900-1940." Explorations in Economic History 20, # 3 (1983): 351-374.

Mowery, David C., and Rosenberg, Nathan. Technology and the Pursuit of Economic Growth. Cambridge: Cambridge University Press, 1989.

Mueller, Dennis. "Patents, Research and Development, and the Measurement of Inventive Activity." Journal of Industrial Economics 15: 26-37.

National Association of Manufacturers, Patents and Research Committee. Trends in Industrial Research and Patent Practices. National Association of Manufacturers, 1948.

National Bureau of Economic Research. The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton, NJ: Princeton University Press, 1962.

National Industrial Conference Board. Mergers in Industry: A Study of Certain Economic Aspects of Industrial Concentration. New York: National Industrial Conference Board, 1929.

National Research Council. Industrial Research Laboratories of the United States, eighth edition. Washington, D. C.: National Research Council, 1946.

National Research Council. Industrial Research Laboratories of the United States, eighth edition. Washington, D. C.: National Research Council, 1930.

National Research Council. Research--A National Resource. Washington, D. C.: U. S. Government Printing Office, 1941.

National Research Council. Research Laboratories in Industrial Establishments of the United States. Washington, D. C.: National Research Council, 1921.

National Research Council. Research Laboratories in Industrial Establishments of the United States. Washington, D. C.: National Research Council, 1920.

Navin, Thomas R. "The 500 Largest American Industrials in 1917." Business History Review, Vol. XLIV, No. 3 (Autumn 1970), pp. 360-86.

Nelson, Ralph. Merger Movements in American Industry, 1895-1956. Princeton, NJ: Princeton University Press, 1959.

Nelson, Richard R. "The Economics of Invention: A Survey of the Literature." Journal of Business 32 (April 1959): 101-27.

Nelson, Richard R. and Sidney G. Winter. An Evolutionary Theory of Economic Change. Cambridge, Massachusetts: The Belknap Press of Harvard University Press, 1982.

Nelson, Richard R. "Evolutionary Modelling of Economic Change." In Stiglitz and Mathewson, eds., New Developments in the Analysis of Market Structure. Cambridge, Massachusetts: The MIT Press, 1986.

Nelson, Richard R. and Winter, Sidney G. "Forces Generating and Limiting Concentration under Schumpeterian Competition." Bell Journal of Economics 9, # 2: 524-48.

Nelson, Richard R. and Winter, Sidney G. "In Search of Useful Theory of Innovation." Research Policy 6 (1977): 36-76.

Nelson, Richard R. "Institutions supporting technical change in the United States," in Dosi et al, eds., Technical Change and Economic Theory (London: Pinter Publishers, 1988.

Nelson, Richard R. and Winter, Sidney G. "The Schumpeterian Trade-off Revisited." American Economic Review 72, # 1: 114-33.

Nelson, Richard. "The Simple Economics of Basic Scientific Research." In Rosenberg, The Economics of Technological Change. Middlesex,England: Penguin Books, Ltd., 1971.

Nelson, Richard R. et al. Technology, Economic Growth, and Public Policy. Washington, D. C.: Brookings Institution, 1967.

Nelson, Richard. Understanding Technical Change as an Evolutionary Process. Amsterdam: Ilsevier Science Publishers, BV, 1987.

Noble, David. America by Design: Science, Technology and the Rise of Corporate Capitalism. New York: Alfred A. Knopf, 1977.

Nutter, G. W. "Monopoly, Bigness, and Progress." Journal of Political Economy 54 (1956): 520-27.

Nutter, G. Warren and Harry E. Adler. Enterprise Monopoly in the United States 1899-1958. New York: Columbia University Press, 1965.

Oliver, John W. History of American Technology. New York: The Ronald Press, Co., 1956.

Olson, Sherry. The Depletion Myth. Cambridge, Massachusetts: Harvard University Press, 1971.

Paine, Albert Bigelow. In One Man's Life. New York: Harper & Bros., 1921.

Parsons, Donald O. and Ray, Edward J. "The U.S. Steel Consolidation: The Creation of Market Control." Journal of Law and Economics XVIII (April 1975): 181-219.

Perazich, G., and Field, P. M. Industrial Research and Changing Technology. Philadelphia: Works Project Administration, National Research Project, Report M-4, 1940.

Phillips, Almarin. "Concentration, Scale, and Technological Change in Selected Manufacturing Industries, 1899-1939." Journal of Industrial Economics (June 1956):

Phillips, Almarin. "Patents, Potential Competition, and Technical Progress." American Economic Review 56 (1966): 301-10.

Phillips, Almarin. Technology and Market Structure. Lexington, Massachusetts: Lexington Books, 1971.

Pursell, Carroll. "Science and Industry." In Daniels, Nineteenth Century America: A Reappraisal. Evanston, Illinois: Northwestern University Press, 1972.

Rae, John. "The Application of Science to Industry." In Oleson and Voss, The Organization of Knowldege in Modern America, 1860-1920, Baltimore: The Johns Hopkins University Press, 1979.

Raymond, Fairfield. "Research--A Resource to Small Companies," in National Research Council, Research--A National Resource, vol. II. Washington, D. C.: National Research Council, 1940.

Redman, L. V. The Romance of Research. Baltimore: The Williams & Wilkins Co., in cooperation with the Century of Progress Exposition, 1933.

Reese, Charles. "Developments in Industrial Research." Speech at the 1918 meeting of the American Society for Testing Materials.

Reese, Charles. "Industrial Benefits of Research." Paper delivered before the Division of Engineering of the National Research Council, February 4, 1921. National Research Council: Reprint and circular series, # 18.

Reese, Charles L. "Informational Needs in Science and Technology." Reprint from Journal of Industrial and Engineering Chemistry 14, # 5 (May 1922): 364.

Reese, Charles L. "Introductory Remarks." Journal of Industrial and Engineering Chemistry 11(1917): 107.

Reese, Charles L. "Twenty-five Years' Progress in Explosives." Journal of the Franklin Institute 198 (1924): 748-49.

Reich, Leonard S. "Industrial Research and the Pursuit of Corporate Stability: the Early Years of Bell Labs." Business History Review 54 (Winter 1980): 504-29.

Reich, Leonard S. The Making of American Industrial Research, Science and Business at GE and Bell, 1876-1926. Cambridge: Cambridge University Press, 1985.

Reich, Leonard S., "Research, Patents, and the Struggle to Control Radio: a Study of Big Business and the Uses of Industrial Research," Business History Review 51, # 2 (1977).

Republic Steel Corporation. The Story of Republic Steel. Cleveland: Republic Steel Corporation, 1943.

Rosenberg, Nathan. "The Commercial Exploitation of Science by American Industry." In The Uneasy Alliance, Clark and Hayes, eds. Boston: Harvard Business School Press, 1985.

Rosenberg, Nathan, ed. The Economics of Technological Change. Middlesex, England: Penguin Books, Ltd., 1971.

Rosenberg, Nathan and L. E. Birdzell, Jr. How the West Grew Rich: The Economic Transformation of the Industrial World. New York: Basic Books, Inc., Publ., 1986.

Rosenberg, Nathan. Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press, 1982.

Rosenberg, Nathan. Perspectives on Technology. Armonk, New York: M. E. Sharpe, 1976.

Rosenberg, Nathan. Technology and American Economic Growth. New York: Harper & Row Publ., 1972.

Ross, Malcolm, ed. Profitable Practice in Industrial Research. New York: Harper & Bros., Publ., 1932.

Salop, S. C. "Strategic Entry Deterrence." American Economic Review 69: 335-38.

Sauveur, Albert. The Metallography and Heat Treatment of Iron and Steel. New York: McGraw-Hill Book Co., Inc., 1926.

Scherer, F. M. Industrial Market Structure and Economic Performance. Chicago: Rand McNally & Co., 1970.

Scherer, F. M. Industrial Market Structure and Economic Performance. Boston: Houghton Mifflin Company, 1980.

Scherer, F. M. Innovation and Growth: Schumpeterian Perspectives. Cambridge, Massachusetts: MIT Press, 1989.

Schmookler, Jacob. "Bigness, Fewness, and Research." Journal of Political Economy, December 1959:

Schmookler, Jacob. "Economic Sources of Inventive Activity." In Rosenberg, The Economics of Technological Change, Middlesex, England: Penguin Books, Ltd., 1971.

Schmookler, Jacob. Invention and Economic Growth. Cambridge, Massachusetts: Harvard University Press, 1966.

Schmookler, Jacob. Patents, Invention and Economic Change. Cambridge, Massachusetts: Harvard University Press, 1972.

Schotter, Howard W. The Growth and Development of the Pennsylvania Railroad Company.

Schroeder, Gertrude. The Growth of Major Steel Companies 1900-1950. Baltimore: Johns Hopkins Press, 1953.

Schumpeter, Joseph A. Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process, vol. I and II. New York: McGraw-Hill Book Co., Inc., 1939.

Schumpeter, Joseph A. Capitalism, Socialism, and Democracy. New York: Harper Torchbooks Edition, Harper & Row, Publ., 1976.

Schumpeter, Joseph A. "The Creative Response in Economic History." Journal of Economic History VII (1947):

Schumpeter, Joseph A. "The Instability of Capitalism." In Rosenberg, ed., The Economics of Technological Change. Middlesex, England: Penguin Books, Ltd., 1971.

Schumpeter, Joseph A. The Theory of Economic Development, trans. Redvers Opie. New York: Oxford University Press, 1961.

Sellew, William H. Steel Rails. New York: D. Van Nostrand Co., Inc., 1913.

Sisco, Frank. "Research in the Iron and Steel Industry," in National Research Council, Research--A National Resource, Vol. II. Washington, D. C.: National Research Council, 1940.

Sklar, Martin. The Corporate Reconstruction of American Capitalism, 1890-1916. Cambridge: Cambridge University Press, 1988.

Smith, W. J. J. and D. Creamer. R&D and Small Company Growth: A Statistical Review and Company Case Studies. New York: National Industrial Conference Board, Inc., 1968.

Smyth, D. J. et al. "Patents, Profitability, Liquidity, and Firm Size." Applied Economics 41: 77-86.

Solo, Carolyn S. "Innovation in the Capitalist Process: A Critique of the Schumpeterian Theory." Quarterly Journal of Economics 65, # 3 (1951): 417-28.

Stevens, Raymond. "Introduction," in National Research Council, Research--A National Resource, vol. II. Washington, D. C.: National Research Council, 1940.

Stiglitz, Joseph F. "Theory of Competition, Incentives, and Risk." In Stiglitz and Mathewson, eds., New Developments in the Analysis of Market Structure. Cambridge, Massachusetts: The MIT Press, 1986.

Stine, Charles M. A. "Change Rules the Rails." An address by Dr. C. M. A. Stine, published by the Chemical Foundation, New York.

Stine, Charles M. A. "Chemical Engineering in Modern Industry," prepared for the joint meeting of the American Institute of Chemical Engineering and the Institution of Chemical Engineers, August, 1928, p. 4.

Stine, Charles M. A. "Chemical Engineering, Technology and Research Work." The Newsletter of the Princeton Engineering Association. June 1925 V, # 4: 114-16, 134, 136.

Stine, Charles M. A. "Chemical Research: A Factor of Prime Importance in American Industry," reprint from Journal of Chemical Education, December 1932.

Stocking, George. Workable Competition and Antitrust Policy. Nashville: Vanderbilt University Press, 1961.

Stoneman, Paul. The Economic Analysis of Technological Change. Oxford: Oxford University Press, 1983.

Stoughton, Bradley. The Metallurgy of Iron and Steel. New York: McGraw-Hill Book Co., Inc., 1934.

Strassman, W. Paul. "Creative Destruction and Partial Obsolescence in American Economic Development." Journal of Economic History 19, # 3.

Strassman, W. Paul. Risk and Technological Innovation. Ithaca, New York: Cornell University Press, 1959.

Swank, James M. History of the Manufacture of Iron in All Ages. Philadelphia, 1892.

Taylor-Wharton Iron and Steel Company. Historically Speaking, 1742-1917. Taylor-Wharton Iron and Steel Company, 1917.

Teece, David J. "Technological Change and the Nature of the Firm." In Dosi et al, Technical Change and Economic Theory. London: PInter Publishers, 1988.

Temin, Peter. Iron and Steel in Nineteenth Century America: An Economic Inquiry. Cambridge, Massachusetts: MIT Press, 1964.

Terleckyj, Nestor E.Research and Development: Its Growth and Composition. New York: National Industrial Conference Board, 1963.

Thompson, Holland. The Age of Invention. New Haven: Yale University Press, 1921.

Thorelli, Hans B. The Federal Antitrust Policy. Baltimore: The Johns Hopkins Press, 1955.

Turner, D. F. and Williamson, O. E. "Market Structure in Relation to Technical and Organizational Innovation." In Heath, ed., International Conference on Monopolies, Mergers and Restrictive Practices. HMSO, 1971.

Tybout, Richard A., ed. Economics of Research and Development. Columbus: Ohio State University Press, 1965.

Unger, J. S. "Some Practical Views of Research," in American Society for Testing Materials, Topical Discussion on Cooperation in Industrial Research. Philadelphia: American Society for Testing Materials, 1918.

Usher, Abbott P. A History of Mechanical Inventions. Cambridge, Massachusetts: Harvard University Press, 1962.

Utterback, J. M. and Abernathy, W. J. "A Dynamic Model of Process and Product Innovation." Omega 3, # 6 (1975):

Vagtborg, Harold. Research and American Industrial Development. New York: Permagon Press, Inc., 1976.

Vanderblue, Homer B. and Crum, William L. The Iron Industry in Prosperity and Depression. New York: A. W. Shaw Co., 1927.

Veblen, Thorstein. "The Technology of Physics and Chemistry," in Absentee Ownership. New York: The Viking Press, Inc., 1923.

Veblen, Thorstein. The Theory of Business Enterprise. New York: A Mentor Book, Publ. by the New American Library, 1932.12

Villard, H. H. "Competition, Oligopoly, and Research." Journal of Political Economy 66 (1958): 483-97.

Von Hippel, E. "The Dominant Role of Users in the Scientific Instrument Innovation Process." Research Policy (1976): 212-39.

Wakasugi, Ryuhei. "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," in Arnold Heertje and Mark Perlman, Evolving Technology and Market Structure. Ann Arbor, Michigan: The University of Michigan Press, 1990.

Weber, Gustavus. The Bureau of Standards, Its History, Activities, and Organization. Baltimore: The Johns Hopkins Press, 1925.

Weston, John Frederick. The Role of Mergers in the Growth of Large Firms. Los Angeles: The University of California Press, 1953.

Whitney, Willis R. "Organization of Industrial Research." Journal of the American Chemical Society 32 (January 1910): 78.

Whitney, Willis R. "Research as a Financial Asset." GE Review 14 (1911): 326-7.

Whitney, Willis R. "Research as a National Duty." Journal of Industrial and Engineering Chemistry 8 (June 1916): 535.

Wiebe, Robert. The Search for Order 1877-1920. New York: Hill and Wang, 1967.

Williamson, J. W. "Industrial Research Laboratories." Nature (1928).

Williamson, O. E. "Dominant Firms and the Monopoly Problem: Market Failure Considerations." Harvard Law Review 85: 1512-31.

Williamson, O. E. "Innovation and Market Structure." Journal of Political Economy 73 (1965): 67-73.

Williamson, O. E. Markets and Hierarchies: Analysis and Antitrust Implications. New York: Free Press, 1975.

Williamson, O. E. "Market Structure in Relation to Technical and Organizational Innovation." In J. B. Heath, ed., International Conference on Monopolies, Mergers, and Restrictive Practices, HMSO, 1971.

Winter, S. G. "Schumpeterian Competition in Alternative Technological Regimes." Journal of Economic Behavior and Organizations (1984):

Wise, George. "A New Role for Professional Scientists in Industry: Industrial Research at General Electric, 1900-1916." Technology and Culture 21 (1980): 408-29.

Wise, George. Willis R. Whitney, General Electric and the Origins of U. S. Industrial Research. New York: Columbia University Press, 1985.

Worcester, Dean A. "Why Dominant Firms Decline." Journal of Political Economy 65 (August 1957): 338-46.

Worley, J. S. "Industrial Research and the New Competition." Journal of Political Economy 69: 183-96.

Worthington, C. G. "Coordination between Industries in Industrial Research," in National Research Council, Research--A National Resource, vol. II. Washington, D. C.: National Research Council, 1940.

Yamawaki, Hideki. "Dominant Firm Pricing and Fringe Expansion: The Case of the U. S. Iron and Steel Industry," Review of Economics and Statistics, August, 1985.

APPENDIX

DESCRIPTION OF PRIMARY SOURCES USED IN THIS DISSERTATION

1. Primary Source Material concerning the Pennsylvania Railroad

Much of the primary source material on the Pennsylvania Railroad used in Chapter 3 was found in the Pennsylvania Railroad Archives at the Hagley Museum and Library in Wilmington, Delaware. The Hagley archives contain voluminous records on every phase of the railroad's operation for the years 1846 to 1960. Records used for this dissertation came from Hagley's files on the Pennsylvania Test and Chemical departments, and consist primarily of correspondence by the directors of the Test department for the years 1910 to 1930, along with articles and sundry records of the Test and Chemical Department during this time.

Other primary source material on the Pennsylvania Railroad came from contemporaneous issues of The Iron Age found in the microform collection of Baker Library at Harvard Business School.

2. Primary Source Material on the American Society for Testing Materials

Primary source material on the American Society for Testing Materials came from two sources. The first source was the annual Proceedings of the Society, which I consulted both at Hodges Library at the University of Tennessee and at Hagley Museum and Library. These volumes contain committee reports and technical papers presented at the

Society's annual meetings. The second source was contemporaneous issues of The Iron Age, again found at Harvard's Baker Library, which reported on the ASTM's annual meetings and provided other related information about the ASTM.

3. Other Primary Source Materials

Other primary source materials used in this dissertation include a large number of articles concerning developments in steel innovation found in contemporaneous issues of The Iron Age at Harvard's Baker Library. As well, the Proceedings of the American Railway Engineering and Maintenance of Way Association were consulted for some additional information on innovation in steel rails.

VITA

Janet Therese Knoedler was born in Springfield, Illinois on July 24, 1955. She attended Little Flower School in Springfield and graduated from Sacred Heart Academy in May, 1973. The following September she entered Springfield College in Illinois, and in May, 1975, received the degree of Associate of Arts degree in Art. She entered Sangamon State University in Springfield in August, 1977, and received the Bachelor of Arts degree in Creative Arts in August, 1979. Upon graduation, she was employed as a statistician in the Office of Institutional Research at Sangamon State University. In 1981 she was promoted to the position of Budget Analyst in the Office of Budget and Planning. She re-entered Sangamon State University on a part-time basis in August, 1983 to pursue a Masters degree in Economics. In 1984 she was promoted to the position of assistant to the Director of Budget and Planning. She received the Master of Arts degree in Economics in December, 1986.

In September, 1987, she entered The University of Tennessee and in December, 1991, received the Doctor of Philosophy degree in Economics. Ms. Knoedler is presently employed as an Instructor in the Department of Economics at The University of Tennessee.